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THE PHYSICAL CHEMISTRY OF THE CRYSTALLIZATION AND MAGMATIC DIFFERENTIATION OF IGNEOUS ROCKS

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VI

THE INFLUENCE OF THE LIGHT VOLATILE COMPOUNDS (H_2O, CO_2, ETC.)

The physico-chemistry of the light volatile compounds in the magmas has lately been explained in two treatises published at the same time and independently of each other, namely:

P. Niggli. Die leichtflüchtigen Bestandteile im Magma. Preisschrift von der Fürstlich Jablonowkischen Gesellschaft zu Leipzig, 1920.

Th. Vogt. Lecture in the Society of Science, Kristiania Meeting, April 16, 1920.

Referring to these two treatises and to H. E. Boeke's "Grundlagen der physikalisch-chemischen Petrographie" (1915, especially pp. 256–63), we will begin with a general orientation.

We will discuss a binary system at constant pressure, in which we think of a very high pressure, between A and B, with melting point, respectively critical temperature, S_A, K_A and S_B, K_B where S_B lies notably higher than K_A (illustrated by Fig. 52). The "critical curve" cuts the curve of the gas phase. In this system, when

applied to the combination H_2O:silicate, the water at a low temperature will only keep dissolved a trifle of silicate. The eutectic point (E in Fig. 52) of the water solution will consequently practically coincide with S_A which is illustrated by the schematic Fig. 53, copied from Th. Vogt's treatise where, under the signature B, we keep together the different silicate components, for instance, in a granite.

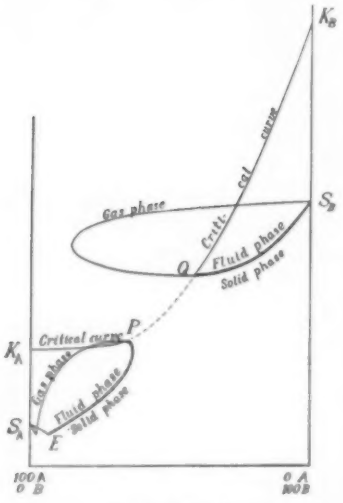

FIG. 52.—The quantitative proportion between A and B as abscisse and the temperature as ordinate.

We may here distinguish between three temperature stages:

1. From S_B (the melting point of the silicate) to Q.

We here get a crystallization of the silicate by continuously decreasing temperature, the quantity of H_2O increasing in the mother liquid (the rest-magma). There is at last produced a magma relatively strongly enriched in H_2O, of the composition Q.

At the same time some of the light volatile compounds escape, so we get a gas phase which can effect pneumatolytic formations. Concerning this we refer to the explanation on the fundamentals given by Th. Vogt and Niggli in Beyschlag-Krusch-J. H. L. Vogt, *Erzlagerstätten*, II, second edition (1921), pp. 555–61.

The gas pressure (the pressure of the escaping gas phase) at S_B (thus for pure B) is very little and increases with the quantity of the light volatile compounds dissolved in the magmatic solution (up to Q). The gases escape when the gas pressure exceeds the external pressure. At a relatively low external pressure, as for the crystallization of a magma at a little depth, the light volatile compounds will consequently escape at higher temperatures, thus also at a relatively earlier stage than at higher pressure, by the

solidification of the magma in a depth, for instance, of 5 or 10 kilometers. And in the last case the escaping gas must dissolve in itself more of the silicate compounds. Th. Vogt applies this to very instructive geological examples.

2. At the temperature interval Q–P there exists a gas (H_2O in supercritical condition with some dissolved silicate in gas-formed condition) from which more or less silicate may crystallize directly from the gas.

3. From P (the critical point of H_2O containing some B in solution, which point lies somewhat higher than the critical point, $K_A = 374°$, of pure H_2O) to E (Fig. 52) or S_A (in Fig. 53, where E and S_A practically fall together) we get a liquid very rich in H_2O, which may effect divers hydrotermal formations. Further on we get a gas phase consisting of quite predominant H_2O and only a very little B.

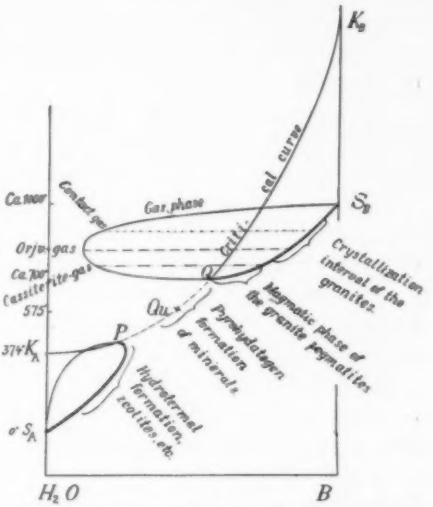

FIG. 53.—System A:B, where A = H_2O and B = silicate (silicates of the granite). Qu = quartz point (inversion points between α and β quartz, at one atmosphere at 575° and at pressure somewhat higher).

The pressure may be indicated by axes perpendicular to the plane of the paper. At relatively low pressure in the deep-seated magmas and consequently at high temperature, contact gas escapes, giving as a result the contact metamorphic ore deposits of the Kristiania type. At higher pressure and consequently at a somewhat lower temperature, contact gases escape with a higher solution of silicates, etc., giving, as a result, contact metamorphism of the Orijärvi type ("Orjv. gas"). After Th. Vogt.

By far-advanced crystallization of the granite magma escape "cassiterite gases" ($Sn F_4$, etc.), giving as a result the minerals of the cassiterite deposits.

We shall in the following pages only treat the *crystallization* in a magma, containing light volatile compounds, and not employ

ourselves with the pneumatolytic, pyrohydatogen, and hydrotermal processes effected by the escaping gas.

During the crystallization of the magma the light volatile compounds will conduct themselves in different ways:

1. Some will, if the gas pressure is sufficiently high, escape from the magma.

2. Some will be inclosed in the crystallizing minerals as gas- or liquid-inclusions (for instance, the well-known pores in quartz, at low temperature chiefly consisting of liquid CO_2).

3. Some may enter in solid solution into the crystallizing minerals. The quantity calculated by weight—or molecular weight—of these "occluded" gases is, however, very little.[1]

4. Some may, under certain circumstances, enter into the crystallizing minerals, for instance H_2O in muscovite, biotite or hornblende, CO_2 in calcspar, etc.

5. The rest of the gas will remain in dissolved condition in the magma and be concentrated in the mother-liquid, by continuously decreasing temperature until it reaches Q.

These light volatile compounds dissolved in the magma exist in the reciprocal solution in the same manner as the other solution-components. If we think of a magma containing mix-crystal components, as Ab and An besides dissolved water, the water will not influence the mix-crystal system. And if we have a ternary system of two components independent of each other, *a* and *b* and also a little water (in lesser amount than that equivalent to Q on Figs. 52–53), the sequence of the crystallization will be between *a* and *b*, dependent on the quantitative relation between *a* and *b* in relation to a eutectic boundary curve, beginning at the binary eutectic E_{a-b}. The further extension of the curve will be stipulated by the third component, H_2O, present in small amount. With a slight quantity of H_2O the relation between *a* and *b* on the boundary curve will be almost exactly the same as in the binary eutectic E_{a-b}. That is to say, the sequence of the crystallization between

[1] By heating to below the melting point of the rocks these occluded gases may escape and thereby break the rock into pieces. In this manner many rocks (granite, syenite, gabbro, etc.) may be completely desintegrated by fire.

a and *b* will be displaced only very inconsiderably by the presence of some dissolved water.[1]

We have here supposed that H_2O enters as an independent component (H_2O). But it may also be thought that H_2O, CO_2, HCl, etc., under certain conditions, partly also may form special combinations (for instance H_2SiO_3, H_4SiO_4, H Al SiO_4, etc.), which may be broken up during the run of the crystallization. Hereby there is a possibility for complications which will be very difficult to explore.

In a binary system (under high pressure) of a light volatile component, as, for instance, H_2O, and a silicate, as Ab, An, Or, Ca Mg Si_2O_4, etc., even a little H_2O will effect a relatively considerable depression of the melting point of the silicate, and this depression is nearly proportional to the quantity of H_2O, etc. We refer to the explanation given by Niggli (1920), pages 34–35, and illustrated by his Figure 2, II and III. And in general, the light volatile components (H_2O, CO_2, HCl, etc.) will effect a tolerably considerable depression of the crystallization interval.

From theoretical reasons it must be presupposed that the light volatile components may effect a very considerable increase of the *thin-fluidity*. This is, as far as I know, not verified by laboratory experiments, but that it is the case, may *inter alia* be proved by the fact that the magma of granite-pegmatite dikes, in spite of the low crystallization interval (about 800°–700°) must have been extremely thin-fluid.

With regard to the quantity of the light volatile components in the various eruptive magmas, we may present the following general consideration.

By crystallization-differentiation in a parent-magma with a certain percentage of light volatile components (as, for instance, H_2O), the first separated crystals will, in most cases because of their increased density, sink into a deeper-lying and higher-heated magma-layer where they are dissolved (or resorbed). As we shall

[1] In this connection we will cite a portion of the conclusion in the treatise of P. Niggli, "Die Gase im Magma" (*Centralbl. f. Min.*, etc. [1912], pp. 337–38). "Es ergiebt sich aus den (physikalisch-chemischen) Versuchen dass in vielen Fällen (hoher Druck) die Gasmineralisatoren wie eine andere Komponente behandelt werden können, dass also Vogt's Ansicht, dass einfache Schmelzflüsse schon viele petrographische Probleme erleuchtern, richtig ist."

see in a later paper, there results from this process, as a rule, after repeated crystallization-differentiations, the *anchi-monomineral magmas* (for example, anorthosite, dunite), where the original quantity of the light volatile compounds in the parent-magma must be considerably diluted.

By the segregation of the anchi-monomineral magmas, the light volatile components, so far as they do not escape, will remain in the rest-magma. Extensive crystallization-differentiation results in *anchi-eutectic magmas* (most gabbros, norites, syenites, granites) and as the *final* product of the differentiation running in the anchi-eutectic direction are brought out the *granitic* magmas.

Consequently, we must a priori presume that the light volatile components on an average will be in the smallest quantity in the anchi-monomineral magmas which must have been "dry" or "almost dry melts." A somewhat higher percentage may generally occur in the anchi-eutectic magmas and indeed especially in the granitic magmas. And in the last ones result, as the final solution at a very great depth (after Th. Vogt) where the light volatile components cannot, or can only in part, escape the granite pegmatitic magmas where we may expect a relatively extensive concentration of the volatile components.

As support to this theoretical deduction we shall first point out that *miarolitic druses*, according to my own field observations, generally are completely lacking in anorthosites, dunites and petrographically related rocks. On the other hand, they are very common in many granites, quartz-syenites, etc., and in the miarolitic druses we often find, as well known, a supply of pneumatolytic minerals proving that these druses must have been genetically connected with the volatile components.

Further, according to my own field observations, tourmaline and other pneumatolytic minerals are completely or almost completely wanting in the Norwegian massives of anorthosite and also in the numerous but certainly, as a rule, very small massives of peridotite. By far the most *magmatic-epigenetic* (pneumatolytic, pyrohydatogen, and hydrotermal) ore deposits are connected with acid or intermediate igneous rocks (granite, quartz monzonites, etc.). These ore deposits are, in relation to the extension of the

igneous rocks, relatively much rarer with basic igneous rocks, and they are, so far as I know, entirely lacking in the often very large massives of anorthosite. As more fully treated in Beyschlag-Krusch-Vogt (*Die Erzlagerstätten*, Vol. II, 2d ed. [1921], pp. 564–65), this may be explained by the relatively high content of volatile compounds in the granitic magmas. And as far as the granite-pegmatite dikes are concerned, these are, as is known, frequently characterized by a very considerable supply of pneumatolytic (or magmatic-pneumatolytic) minerals.

We further get very instructive information in investigating the relations between *orthorhombic* and *monoclinic pyroxene* on the one hand, and *hornblende*, *biotite* and *muscovite* on the other, in the various rocks.

As is known, muscovite is noted by Tschermak with the formula $KH_2Al_3(SiO_4)_3$ and biotite (meroxene) with $K_2HAl_3(SiO)_4 \cdot nMg_2SiO_4$, where n is 3 or at times somewhat lower. Some of K usually is replaced by Na, and especially in biotite some of Al by Fe and some Mg by Fe. Further some F commonly enters into the mica, replacing O (or HO?). The relation between K and H moreover, is subject to certain variations. These standard formulas prove that the muscovite contains considerably more H_2O[1] than the biotite. Primary muscovite from granite-pegmatite dikes (and granite) contains, according to the analyses at hand, mostly 5–8 per cent H_2O and 11–9 per cent $K_2O + Na_2O$, and the biotite from granite and other acid igneous rock, mostly 1–2 à 2.5 per cent H_2O and 9–7 per cent $K_2O + Na_2O$.

Also the hornblende commonly carries some H_2O (or HO), viz., in the igneous rocks at most 2 per cent, usually considerably less, and tremolite up to 2.5 per cent.

As to the conditions for the formation of biotite in the igneous rocks, we refer especially to the account given by N. L. Bowen[2] and to the treatise of P. Niggli,[3] "Die gasförmigen Mineralisationen im Magma."

In the previously (pp. 430–35) described orbicular quartz-norite from Romsaas, consisting of *ca.* 63 per cent hypersthene, 8 per cent biotite, 24 per cent plagioclase (on an average $Ab_{42}Or_3An_{55}$), 4 per

[1] Here and in the following I do not enter upon the question on whether it is hydroxyl, HO, or H_2O, which appears.

[2] "The Later Stages of the Evolution of the Igneous Rocks," *Jour. of Geol.* (1915).

[3] *Geol. Rundschau*, III (1912).

cent quartz, and a little rutile and apatite, the individualization began with the crystallization of hypersthene in large quantities. Then followed, during a short stage, a simultaneous crystallization of hypersthene and biotite, while the Mg, Fe-silicate present in the magma during the last stage entered totally into the biotite.

The *anhydrous meta*-silicate *hypersthene* thus during the later stage of the crystallization—even after the percentage of SiO_2 in the residual magma was quite considerably increased, viz., to about 61 per cent—was replaced by the *hydrous ortho*-silicate *biotite*. This must be due to the fact that the original percentage of H_2O of the magma was so small, that at first hypersthene could be formed. But when a considerable quantity of this mineral was segregated H_2O became so strongly concentrated that biotite also could be formed. And during the last stage, when the remaining mass was reduced to *ca.* $\frac{3}{10}$ of the entire rock, the quantity of H_2O was thus very considerably increased, so that the formation of hypersthene ceased, and biotite was formed instead.

As we shall treat more particularly in a later paper, there occur, in the quartz-norite massive at Romsaas, a number of pegmatitic "Schlieren" and dikes of nearly the same mineral composition as the intervening mass between the orbs of the orbicular norites, but with the plagioclase ($Ab_{68}An_{32}$) somewhat richer in Ab and with somewhat more quartz. These pegmatitic "Schlieren," etc., must represent the end-magma, resulting from a very late stage where the quantity of H_2O was still more concentrated. This is in accordance with the pegmatitic structure and moreover with the fact that the Mg, Fe-silicate here only enters into biotite, while hypersthene is entirely lacking.

In several norites from Norwegian localities examined by me, biotite is entirely lacking in almost all thin sections from one single field (Ertelien on Ringerike) while a little biotite occurs in most fields, mostly 2, 3, 4, or 5 per cent, and only as a rare exception, as in the quartz-norite from Romsaas, as much as 8 per cent. Where both hypersthene and biotite occur, the last one always, as just described from Romsaas, belongs to a somewhat later stage than the hypersthene. It is especially to be emphasized that neither the absolute quantity of biotite nor the quantitative proportion

between biotite and hypersthene stands in any relation to the composition of the rocks determined by the quantitative chemical analysis. The formation of biotite thus is not dependent on the content of K_2O in the rocks nor on the proportion of K_2O to MgO (or MgO+FeO). In some norites with 0.5–0.7 per cent K_2O the entire quantity of K_2O enters into the feldspar (as $KAlSi_3O_8$ in the plagioclase). In other norites with the same percentage of K_2O, as much as *ca.* $\frac{6}{7}$ of the content of K_2O of the rock may enter into the biotite and only $\frac{1}{7}$ into $KAlSi_3O_8$ of the plagioclase. When we consider this in the light of all the other observations here treated, the conclusion clearly is justified that the cause of the greatly varying quantity of biotite in these rocks must be due to the variations in the quantity of H_2O in the magma. But even in those norites that carry as much as *ca.* $\frac{1}{6}$ of biotite in proportion to the sum of hypersthene and biotite, the H_2O percentage in the magma must have been rather small.

As earlier mentioned, many Norwegian norites and gabbros do not contain any primary hornblende at all, and where this mineral occurs it is somewhat younger than the pyroxene (p. 521). We may here apply the same considerations as those regarding the relation between the hypersthene and biotite in the quartz norite from Romsaas.

The anorthosites constantly carry, as is well known, a small admixture of hypersthene, or sometimes of augite (diallage) and olivine, while primary hornblende seems to be entirely lacking.

As we shall show in a later paper, the peridotite series in the first stage of concentration—carrying about 35–50 per cent olivine and with a chemical composition 41–49 per cent SiO_2, 5–10 Al_2O_3, 6–10 CaO, 0.25–2 alkalies, 10–15 FeO, and 15–25 MgO, thus about 0.75 MgO:0.25 FeO—in almost every case is characterized by some primary hornblende, at times also by some primary biotite. In the progressive concentration of the olivine—and simultaneously with diminishing percentage of Al_2O_3, CaO and alkalies and increasing Mg_2SiO_4 in proportion to Fe_2SiO_4—the hornblende is, on an average, diminishing in quantity and in peridotite rocks with at least 85–90 per cent olivine hornblende as a primary formation is entirely or almost entirely lacking.

The formation of the minerals in both the anorthosites and the olivine rocks—with at least, respectively, *ca.* 90 per cent plagioclase (labradorite-bytownite) and 85–90 per cent olivine (poor in iron)—thus indicates a crystallization of a magma very poor in H_2O.

As to the relation between *hypersthene*, *biotite*, and *biotite+muscovite* in the *alcali granites*, we shall as a beginning cite a very instructive statement by H. Rosenbusch (*Mikroskop. Phys. d. Massigen Gesteine*, II, 1 [1907], p. 71): "Die Analyse eines Hypersthengranites und eines gewöhnlichen normalen Alkaligranite sind nicht sicher zu unterschieden."

In granites with composition

73–77	per cent	SiO_2
11–15	"	Al_2O_3
1.5–3	"	Fe_2O_3+FeO
0.2–0.7	"	MgO
0.25–1.4	"	CaO
5–8	"	$K_2O+Na_2O_4$

(with varying proportion of K_2O and Na_2O) we find, in some cases, though rather rarely, hypersthene—in by far the most cases biotite—and at times biotite+muscovite.

In the hypersthene-granite from Birkrem and environs in the Ekersund Soggendal-field, the hypersthene (opt. neg.), according to my determination, shows axial angle *ca.* 70°, the composition is thus *ca.* 0.64 $MgSiO_4$:0.36 $FeSiO_4$ (equivalent to about 23 per cent MgO and 18 per cent FeO). The quantity of hypersthene in this rock (with *ca.* 73–75 per cent SiO_2) according to microscopical examination is quite small, about 1 per cent, corresponding to *ca.* 0.2–0.25 per cent MgO+0.2 per cent FeO. An analysis published by C. F. Kolderup[1] shows 73.47 per cent SiO_2, 0.12 TiO_2, 15.42 Al_2O_3, 1.02 Fe_2O_3 (including FeO), 0.20 MgO, 1.35 CaO, 5.57 Na_2O and 3.64 K_2O, thus stoechiometric 0.70 Na_2O:0.30 K_2O. The three analyses of charnockite (hypersthene-granite) from Madras[2] (India) with 75.3–77.5 per cent SiO_2, on the other hand show in part a middle

[1] Das Labradorfelsgebiet bei Ekersund und Soggendal, *Bergens Museums Aarbog* (1896), p. 96.

[2] Cited from H. S. Washington, *Chemical Analyses of Igneous Rocks*, 1884–1913 (1917, pp. 88 and 956).

proportion of Na_2O to Ka_2O, and in part predominantly K_2O, viz., almost 0.7 K_2O:0.3 Na_2O. We shall group the contents of MgO and K_2O in the just-mentioned analyses of hypersthene-granite with 73.5–77.5 per cent SiO_2:

per cent MgO	0.20	0.43	0.69	0.60
" K_2O	3.64	4.14	3.34	6.13

It appears from this that the formation of hypersthene in these alkali-granites is not dependent on any especially high percentage of MgO (or MgO+FeO) nor on an especially low percentage of K_2O.

According to my examinations of some Norwegian "white granites," relatively rich in acid plagioclase (according to the nomenclature of V. M. Goldschmidt[1] "Trondhjemite") from the north of Norway carrying both *muscovite* and *biotite*, the muscovite occurs exactly in the same way as the biotite. Especially it is to be emphasized that the muscovite-individuals frequently are congested in small aggregates—they thus show "together swimming structure" (synneusis structure) indicating formation at a very early stage—and they are in more places deposited on the small apatite-crystals which serve as "Fixkörper." Some individuals show idiomorphous contours parallel to 001, as well as perpendicular to 001, against the quartz and the feldspar. Most frequently occur the usual lobed outlines, however, as in most of the individuals of biotite in granite.

In some of these muscovite-bearing granites, as, for instance, in a rock from Narvik—with twice as much muscovite, in leaves up to 3 mm. in size, as biotite—we observe crystallographically parallel growths, at times in alternating strata of the two mica-minerals, as described by Rosenbusch (*op. cit.*, p. 57).

In other samples, however, as in a rock from Fustervand near Mosjöen, with nearly twice as much biotite as muscovite—the last one in leaves only *ca.* 1 mm. in size—we observe individuals of muscovite with idiomorphic contours inclosed in the biotite, indicating that the muscovite at least for a great part was formed at an earlier stage than the biotite.

[1] "Geologisch-petrographische Studien im Hochgebirge des Südlichen Norwegens," *Ges. d. Wiss.*, Kristiania (1916).

Rosenbusch (*op. cit.*, p. 51) maintains the view that the formation of muscovite in the granite must be explained as a pneumatolytic process[1] "worauf auch seine weite Verbreitung in den Pegmatiten deutet." This may perhaps to a certain extent be adequate for the muscovite, which belongs to miarolitic druses, but it cannot be applied to the common muscovite evenly distributed in the granite. The structure proves that the muscovite has crystallized from the magma at a very early stage, in part at the same time and in part somewhat earlier than the biotite.

Whether hypersthene, biotite, or biotite and muscovite shall crystallize in acid granites with *ca.* 75 per cent SiO_2 does not depend upon the presence in the magma of those compounds that are shown by the quantitative chemical analysis, nor upon certain variations with regard to pressure, time of cooling, etc. When to this are added the facts that muscovite as a primary formation in igneous rocks is limited to granite-pegmatite dikes and to some granites, and that muscovite is characterized by relatively much H_2O, biotite by a smaller percentage of H_2O, and hypersthene by no H_2O at all, we must conclude that the decisive factor is the varying content in the magma of H_2O (eventually also other volatile compounds).

In the two-mica-granites examined by me, there is up to about twice as much muscovite as biotite. If we turn to the granite-pegmatite dikes, however, we find at times, though very rarely, as in the case of some districts of Smaalenene in Norway, muscovite only, without any biotite at all, and the quantity of muscovite may here rise to as much as about 10 per cent.

The great majority of alkali-granites are characterized by biotite. Two-mica-granites, in Norway as elsewhere in the world, are rare, and hypersthene-granites, so far as yet known, are still more rare.

The content of H_2O in the granite-magma thus in most cases must have been lying within the interval that gives biotite. As a

[1] While H_2O dissolved in the magma appears in the same manner as the other components, I do not find it natural or right to extend the meaning of the term pneumatolysis to include the formations of minerals, as biotite or muscovite where the magmatic dissolved H_2O was co-operant.

rare exception only, the quantity of H_2O may have been so small, that hypersthene has been formed (or, principally in somewhat more basic granites, a monoclinic pyroxene, besides or instead of hypersthene), and relatively seldom only the content of H_2O, etc., was somewhat higher, so that muscovite was formed together with biotite. In granite-pegmatite dikes of analogous chemical composition the content of H_2O, etc., throughout must have been considerably higher, as we here never find hypersthene or diopside, but mica and not seldom muscovite together with biotite, occasionally even muscovite alone without biotite.

And if we further draw a parallel between the granites (with *ca.* 75 per cent SiO_2) on the one hand and norites, gabbros, anorthosites, etc. (with *ca.* 50 per cent SiO_2), on the other, we will find that mica plays a predominant part in the first-mentioned acid rocks, while in the last-mentioned basic rocks biotite is much more subordinate than the pyroxenes, and muscovite is entirely lacking.

By three different methods of investigation, viz., in the study of the distribution of miarolitic druses, in the study of the magmatic-epigenetic formations of ore deposits, etc., connected with igneous rocks, and in the study of the relation between mica (biotite, eventually also muscovite), and in part also hornblende, and pyroxene, we thus get a confirmation of the theoretically drawn conclusion that the granites on an average contain the highest percentage of H_2O, etc.

Then we come to the question of how much H_2O, etc., there may have been present at the start of the crystallization in the magma and especially in the granite-magma.

In the muscovite granite-pegmatite dikes there may occur about 10 per cent muscovite containing 5–8 per cent H_2O. In proportion to the entire magma there thus entered into the *early* crystallizing mica *ca.* 0.5–0.8 per cent H_2O. But still there must have been present so much H_2O that the later separated minerals might also obtain the pegmatitic structure. This quantity of H_2O (with CO_2, etc.) escaped, except those small quantities that entered into the microscopic pores or was occluded in the separating minerals. This, including the content of H_2O in the mica, will only make 1 per cent by weight of the entire magma. The gas that escaped in the

course of the crystallization, at least in part, will have formed miarolitic druses. These play a rather subordinate part in regard to the quantity in the granite-pegmatite dikes, however.

Even in the granite-magma the quantity of H_2O will hardly have amounted to much more than a few per cent. And the crystallization of the igneous rocks must, as pointed out by many earlier investigators, among them also myself, be conditioned by the decreasing temperature of the magma and not by the diminution of volume occasioned by the escaping H_2O, etc.

According to Clarke's well-known calculation the earth's crust consists to a depth of 10 miles (=*ca.* 16 km.) at a medium density of the rocks of 2.7, of

93.39	per cent	solid crust,	with 2.02 per cent H_2O
6.58	"	" ocean,	with *ca.* 97 per cent H_2O
0.03	"	" atmosphere	

If we were to presume that the entire quantity of water of the ocean was supplied from the igneous magmas, and assume a medium thickness from the solid crust of three times 10 miles=*ca.* 48 (or 50) km., we would get a quantity of H_2O:

$$\tfrac{1}{3}\times 6.58\times 0.97+97.81\times 2.02=4.06 \text{ per cent } H_2O.$$

This value, *ca.* 4 per cent, must indicate the maximum original content of H_2O in the initial parent-magmas. But of this again a considerable part must have escaped before the parent-magmas could have been cooled so far that crystallization-differentiation began. The various partial magmas, resulting from magmatic differentiation, which, crystallized to form the igneous rocks, must thus, on an average, have contained less, very likely quite considerably less, than 4 per cent H_2O.

In concluding, I wish to note that I have learned much from P. Niggli's great work: "Die leichtflüchtigen Bestandteile im Magma" (1920), but I cannot endorse his statement (pp. 123–38) that the volatile compounds have been the important factor in magmatic differentiation. This will be more closely treated in a later paper.

[*To be continued*]

THE PLEISTOCENE HISTORY OF THE LOWER WISCONSIN RIVER[1]

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INTRODUCTION

The Wisconsin River, rising among the glacial lakes in the northern part of the state of Wisconsin, flows almost due south nearly to Portage, where it turns and flowing westward for a distance of about 80 miles joins the Mississippi just south of Prairie du Chien (Fig. 1). It is this lower, east-west part of the river valley which is discussed in this paper. The terminal moraine of the Wisconsin glacial epoch crosses the valley just east of Prairie du Sac and marks not only the eastern boundary of the region here considered but also that of the driftless area. Since glacial drift is found in Iowa opposite the lower end of the valley, it may be said that the Wisconsin River traverses from east to west the entire driftless area. It is thus seen that drift remnants which are found in this part of the valley are of important significance in the history of ancient ice invasions in bordering regions.

These remnants of glacial drift in the valley fall naturally into two divisions: First, there are terraces of Wisconsin age: (*a*) remnants of the valley train sloping from the terminal moraine, where it crosses the valley near Prairie du Sac, to the Mississippi River, and (*b*) a lower terrace standing only 15 feet above the present river flood-plain; and second, standing well above the preceding terrace, are rock benches covered with much older drift. These upper benches have a gentle slope toward the east (Fig. 2).

PART I. OLDER DRIFT

Stated in the simplest terms, there are six areas of the older drift: (1) near Lone Rock, (2) near Muscoda, (3) from Muscoda to Boscobel, (4) from Boydtown to the Kickapoo River, (5) at

[1] Condensed from Ph.D. thesis submitted to the Department of Geology, the University of Chicago, 1920.

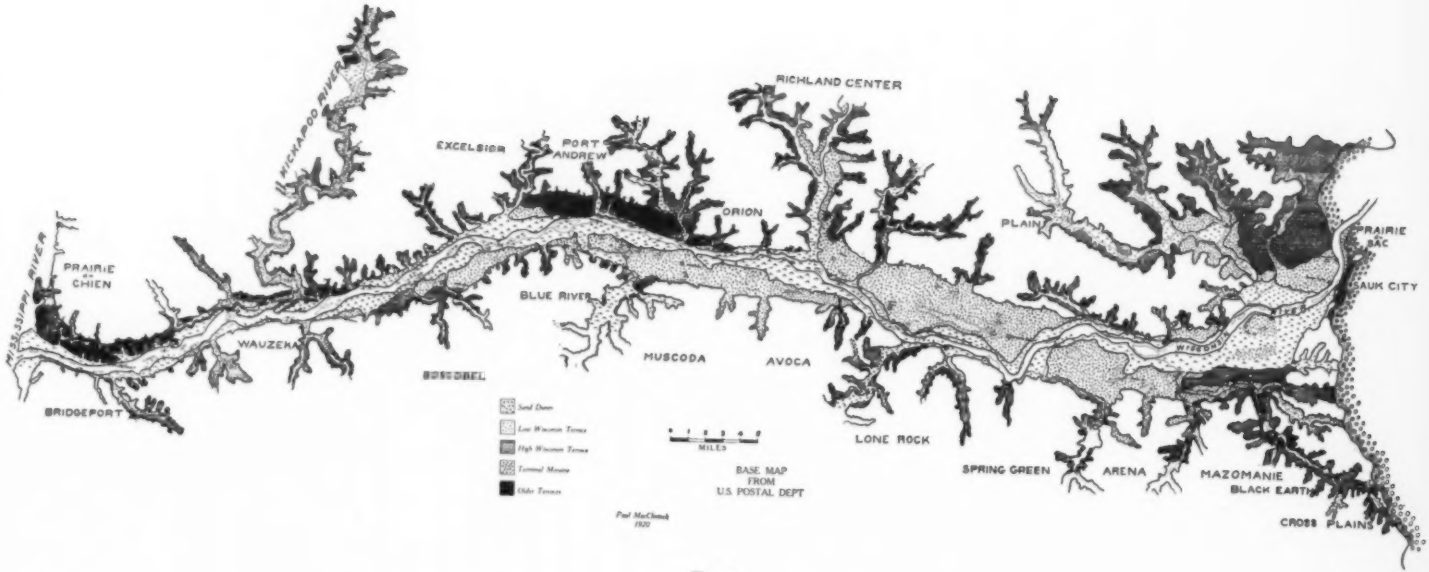
MISSISSIPPI RIVER
PRAIRIE DU CHIEN
WISCONSIN RIVER
EXCELSIOR
PORT ANDREW
RICHLAND CENTER
ORION
BLUE RIVER
WAUZEKA
MUSCODA
AVOCA
PLAIN
PRAIRIE DU SAC
SAUK CITY
WISCONSIN RIVER
BRIDGEPORT
LONE ROCK
SPRING GREEN
ARENA
MAZOMANIE
BLACK EARTH
CROSS PLAINS
Sand Dunes
Low Wisconsin Terrace
High Wisconsin Terrace
Terminal Moraine
Older Terrace
MILES
BASE MAP FROM U.S. POSTAL DEPT
Paul MacClintock 1920

FIG. 1

Wauzeka, (6) at Bridgeport. The first four of these are similar in topography, constitution, and amount of weathering, while the last two differ from the others in that they contain not only much striated material (at Bridgeport) but also a large percentage of calcareous material.

1. SUBDIVISION

It appears from the evidence that the older drift is not all of the same origin or age.

a) A lithologic study of some 300 characteristic rock specimens collected from the different exposures, and examined in the laboratory, shows 37 common to Wauzeka and Bridgeport, 17 common to

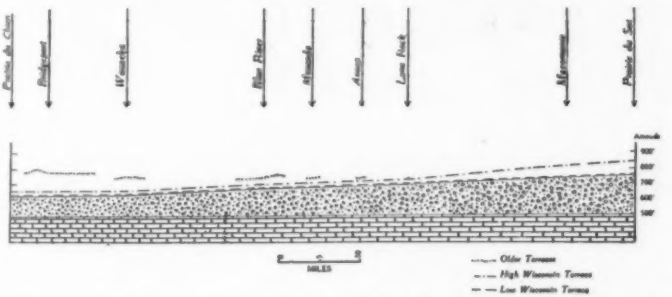

FIG. 2.—Profile of the Wisconsin River Valley from Prairie du Sac to Prairie du Chien showing the bedrock, the drift partly filling the valley, and the levels of the three terraces.

Orion (Port Andrew) and the nearest Illinoian drift at Verona, 9 miles southwest of Madison, 27 common to Orion and Wauzeka, and 25 common to Bridgeport and Iowa (near McGregor). These facts show that there is close similarity between the drifts of Illinoian age and that at Orion on the one hand, and between the drift at Wauzeka, Bridgeport, and Iowa on the other.

b) The drift at Wauzeka and Bridgeport contains much limestone and dolomite, while farther up the valley there is neither. Since the Illinoian and pre-Illinoian drifts east of the region contain calcareous material, it is likely that these terrace deposits in the mid-course of the valley originally contained the carbonates which have been subsequently leached.

c) There is well-developed cross-bedding at Blue River dipping westward, while at Wauzeka, less well-developed but still recognizable cross-bedding in sandy layers dips eastward (Fig. 3).

d) While there are numerous bowlders in the drift of the mid-course of the valley, there are more to be seen at Wauzeka and Bridgeport.

FIG. 3.—Westward dipping gravel on the high terrace two miles northeast of Blue River.

e) On the Bridgeport terrace the stones are not only more angular than elsewhere in the valley, but numerous subangular and striated ones are found. In fact these glaciated stones are as numerous on this terrace as in the till either in Iowa or at the eastern end of the region.

The suggestion from this evidence is that the drift in the mid-course of the valley is fluvio-glacial and from the east, while that at Bridgeport is glacial, and that at Wauzeka is fluvio-glacial and both the latter are from the west.

2. MID-COURSE DRIFT

a) Origin.—The cross-bedding at Blue River makes it evident that the drift in the mid-course was brought in from the east (Fig. 3). This being the case, the upper surface of these terrace deposits should slope conspicuously toward the west, for, while large bowlders so common in most of the exposures may have been carried in bergs, the mass of the material is fluvial and must have been transported by a glacial river—a river having powerful current and fairly steep gradient. A steep gradient may well be postulated for such a glacial river, for there appears, if the bedrock floor of the valley be considered, to have been down-warping at the eastern end of the region. The bedrock in the valley bottom near Prairie du Sac has an altitude of something less than 500 feet,[1] while at Prairie du Chien, near the mouth, its altitude is 490 feet, making a gradient of only two inches to the mile (Fig. 2). The preglacial river with so low a gradient as this could not have eroded so deep and narrow a valley as the rock bottom of this part of the Wisconsin Valley appears to be. The unavoidable inference is that the eastern end of the region must have been higher in preglacial and possibly early glacial times, and must have subsided before the last glacial advance. Data from neighboring regions also suggest that such warping has taken place.[2]

b) Age.—Old drift has been described on the eastern margin of the driftless area by Leverett, Weidman, and Alden,[3] and called by them pre-Illinoian in age. The absence of calcareous material in the old drift in the mid-course of the Wisconsin Valley, even where seen 10 and 12 feet below the surface, suggests that it is as old as Kansan and probably older, i.e., the outwash from the first ice advance.

3. WESTERN DRIFT

a) Origin.—The drift on the Bridgeport terrace must be either glacial or fluvio-glacial in origin. The large number of striated and

[1] W. C. Alden, *U.S. Geol. Surv. Prof. Paper 106* (1918), Plate II.

[2] W. C. Alden, *op. cit.;* F. Leverett, *Journal of Geology*, Vol. III (1895), p. 740; E. W. Shaw, *Bull. Geol. Soc. Amer.*, Vol. XXVI (1914), p. 67.

[3] F. Leverett, *U.S. Geol. Surv. Monograph 38* (1899), pp. 109–10; S. Weidman, *Wis. Geol. Surv., Bull. 16* (1907), p. 433; W. C. Alden, *op. cit.*, p. 168.

subangular stones found nowhere else in the outwash material of the valley, together with the patchy character of the drift, suggests deposition directly by the ice. If this view is correct the glacier must have extended from Iowa across the Mississippi into the lower end of the Wisconsin Valley.

On the other hand, at no place where this older drift occurs was a glacial pavement seen. The drift lies in most places on deeply eroded and weathered dolomite, while at other places several inches of blue-black clay, weathered from the bedrock, lies at the base of the brown drift. It is not strange that, in exposures so limited, no pavement was seen; none has been found in Iowa in this vicinity, where the ice is known to have stood to the very edge of the Mississippi Valley. It seems probable that if a tongue of ice projected into the Wisconsin Valley for a distance of 4 miles—a condition called for by this hypothesis—it would have been at least as wide as the mouth of the valley (1½ miles) so that its shoulders would have rested against the valley walls near the mouth, and have left there glacial material. Some material of this kind is seen for a distance of 1½ miles north of the lower end of the Wisconsin Valley. It is however small in size, meager in quantity, and found not strictly on the shoulders but on the lower slopes at heights of never more than 100 feet above the flood-plain. Glacial material on slopes so steep as the shoulders present would not have remained there but would have soon been washed to the flat below.

The crucial points are: (1) the Bridgeport drift is much higher in altitude than any of the older drift farther up the valley, (2) it is composed of striated, subangular, and grooved material, and (3) it is both stratified and unstratified—the latter material indistinguishable from till. The conclusion then is that this drift is glacial in origin and was deposited by a tongue of ice. It seems clear that the drift at Wauzeka is the outwash material from the same ice invasion, for it is closely akin to the Bridgeport drift in many ways, has the lense and pocked structure of outwash material, and has a suggestion of eastward dipping cross-bedding (Fig. 4). None of this calcareous drift is found farther up the valley because the decline of this old valley train would have brought its top below the level of the rock benches where drift is now found.

This hypothesis involves a damming of the Mississippi River by the ice tongue at the mouth of the Wisconsin. Under this condition the Mississippi must then have flowed between this ice tongue and the northern wall of the Wisconsin Valley and thence eastward to the Rock River or more probably the Lake Michigan Basin. Such an eastward flowing river, if the bedrock divide near Portage had about the present altitude of 600 feet,[1] would have

FIG. 4.—View of the outwash material on the high terrace at Wauzeka showing lenses of sand in the gravel.

had a gradient of about 2.5 feet per mile, or a foot per mile greater than that of the present Wisconsin River. This suggests that the down-warping of the eastern part of the area, mentioned above, had already taken place. It seems, in fact, quite probable that this eastern part of the region was lower than it is at present, for post-Champlainic uplift and warping in the Great Lakes area probably raised the divide from some lower elevation to its present altitude. Since such down-warping as first mentioned has been found in

[1] W. C. Alden, *op. cit.*, Plate II.

neighboring regions, it seems well to note it here, and by so doing possibly to fix the date of the warping—after the first ice invasion at the east of the area and before the second invasion on the west.

Additional evidence of such a displacement of the Mississippi might be expected in old channels. In the eastern part of the valley, Wisconsin glaciation has destroyed any possible trace, while at the west the river was either displaced for so short a time, or subsequent erosion has been so great that there is no evidence of a channel occupied during the displacement. No channel is found in Jo Daviess County, Illinois, where a similar tongue of ice pushed across the Mississippi Valley from Iowa and left drift near Hanover.[1]

b) *Age.*—Two drift sheets, the Kansan and the pre-Kansan, are thought to be present in Iowa near the mouth of the Wisconsin River.[2] The western drift in the Wisconsin Valley must be correlated in age with one of these. The former drift sheet is less weathered than the latter, which is represented, according to present determinations, only by scattered and very much weathered erratics. Judging from the thickness (20 to 50 feet), and from the large content of limestone and dolomite, it seems most probable that the Bridgeport and Wauzeka drift is of Kansan age.

PART II. WISCONSIN DRIFT

1. The terminal moraine of the last glacial invasion extends southward from the Baraboo Range, crossing the Wisconsin River $1\frac{1}{4}$ miles northeast of Prairie du Sac. On the south side of the river it maintains a southerly direction to Black Earth Creek which it crosses $1\frac{1}{4}$ miles east of Cross Plains. North of the river this moraine is a belt showing morainic topography, while south of the river it is in most places a narrow distinct ridge strewn with bowlders. Where it crosses the river the section shows 60 feet of cross-bedded sand with small lenses of fine gravel, overlain, with a sharp contact, by 30 feet of till. The sharp contact shows no weathering. This sand may be outwash from an early Wisconsin moraine farther east or may be the outwash deposited in front of the advancing late Wisconsin ice.

[1] E. W. Shaw and A. C. Trowbridge, *Ill. State Geol. Surv. Bull. 26* (1916), p. 87.

[2] A. C. Trowbridge, *Bull. Geol. Soc. America*, Vol. XXVI (1914), p. 76.

2. Sloping gently westward from the moraine north of the river a sandy outwash plain extends to an irregular boundary against the sandstone hills of the country rock. The western edge is irregular, for the fluvio-glacial material is found up the valleys of Honey and Otter creeks. Of special interest are the erratics found in the south branch of Honey Creek as far west as Blackhawk and Plain. They lie on an upper terrace, corresponding in elevation to that of the outwash plain across the mouth of the creek at its eastern end. This position, 17 miles beyond the terminal moraine, implies that the bowlders were carried to their positions while frozen in blocks of ice floating on a lake.

Such a lake may have been formed in one of two ways:

a) The edge of the ice may have extended beyond the terminal moraine and dammed the mouth of Honey Creek. No evidence was found to substantiate this possibility.

b) As the outwash plain was being built, the glacial waters issuing from the ice-front between Prairie du Sac and the South Range swept their load southward across the mouth of Honey Creek. Outwash material may thus have dammed the mouth of Honey Creek, forming a lake upon which icebergs may have floated the bowlders. While this suggestion involves the difficulty of getting the bergs swept across the outwash plain and into the lake, it still seems the more probable of the two.

3. The valley train, now represented by terrace remnants, once filled the bottom of the valley from the terminal moraine to the Mississippi River. It was 90 feet above the present flood-plain near the terminal moraine, 30 feet in mid-course, and 40 feet at the western end of the valley. As this outwash deposit was growing, the glacial waters constantly deposited material across the mouths of the tributary valleys, causing them in turn to aggrade their channels. Terrace remnants of these slack-water deposits are to be seen in most of the tributary valleys, serving to project the level of the valley train even where it has been removed from the main valley by subsequent erosion.

The most easterly remnant of the original valley train lies near Mazomanie at the mouth of Black Earth Creek. It is an irregular area a mile wide by 6 miles long, separated from the south bluffs

by Black Earth and Halfway Prairie creeks. The surface of this area is gently rolling and marked here and there by patches of low sand dunes. This terrace level extends eastward into Black Earth and Halfway Prairie valleys while the two intervening shorter valleys have this high fill only at their very mouths. This relationship is of importance in connection with the problem, later to be considered, of the age of the terrace.

From Mazomanie for a distance of 30 miles to the west, the upper part of the valley train has been entirely removed from the main valley. The terrace level is, however, present in most of the tributary valleys; notably Blue Mounds, Wyoming, Otter, Pine, Eagle, and Kickapoo creeks. But there are several tributary valleys (see Fig. 1) lacking this terrace level, a fact whose significance is later to be considered.

The remnants of this level, the high Wisconsin terrace, are again found in the main valley near Muscoda and Blue River where the bench is protected by a subjacent ledge of sandstone against which the river is at several places flowing. At Boscobel a large terrace remnant lies against the south wall of the valley. In these latter terrace patches the material is smaller in size and contains fewer limestone pebbles than farther up the valley.

4. Twelve to 15 feet above the Wisconsin River flood-plain and extending short distances up the valleys of many of its tributaries there is an extensive sandy terrace—the low Wisconsin terrace. From the terminal moraine at Prairie du Sac to Wauzeka, a distance of 65 to 70 miles, it is nearly continuous in the main valley on one side of the river or the other, while from Wauzeka to the Mississippi it occurs only in small detached areas. Remarkable uniformity in height above the river is one of its most notable characteristics, for the variation is not more than a foot or two throughout the whole distance. A second notable feature is that the material, where seen in shallow cuts, is uniform in size and constitution through the whole length of the valley, being mostly sand with small pebbles scattered rather uniformly through the mass. The surface of this terrace is in general very flat, but in detail it is seen to have irregularities produced by the wind, such as sand dunes and "blow-holes." Considerable dune areas are found in the neighborhood of Lone Rock and Spring Green. In fact, the whole terrace is so

sandy and so poor as farm land that it is called locally "Prairie" or "Barrens."

There are three possibilities to be considered in discussing the origin of the low terrace: It is either the valley train of the late Wisconsin ice advance or was cut from the early Wisconsin valley train by waters from a glacial lake, or is a combination of the two.

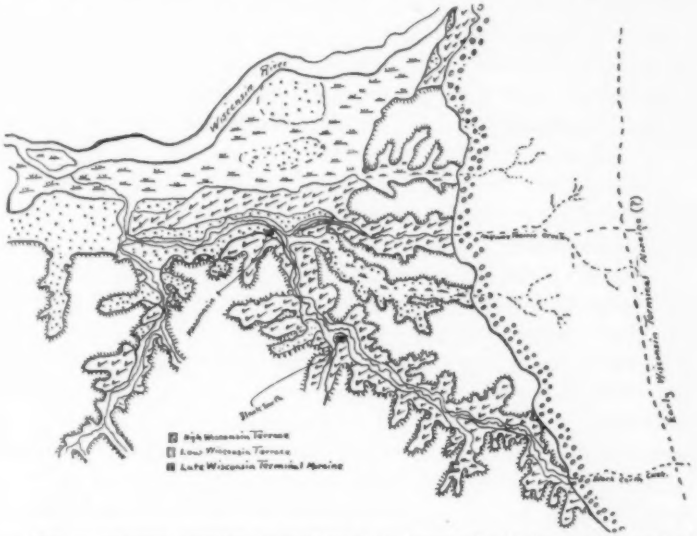

FIG. 5—Diagram showing the relation of the terraces in the four valleys east of Mazomanie. Black Earth and Halfway Prairie creeks contain the high terrace while the two shorter valleys do not.

a) Alden is of the opinion that the low terrace is the result of deposition by glacial waters from the late Wisconsin invasion, while the upper terrace resulted from the early Wisconsin advance.[1] The evidence is as follows: Of the four small valleys east of Mazomanie, the two longer ones contain the upper terrace while the shorter ones do not.[2] This, Alden interprets as meaning that the ice of the early Wisconsin invasion did not reach the heads of the shorter valleys, discharging its waters only through the longer ones and building in them the high terrace (Fig. 5).

[1] W. C. Alden, *op. cit.*, pp. 191–93 and 244–45.

[2] The northern one does contain several small patches (see Fig. 5).

Following the retreat of the early Wisconsin ice came a period of erosion during which part of the fill was cut away. The late Wisconsin ice advanced farther and stood across the heads of all four valleys, building valley trains at the level of the low terrace. At the same time the low terrace was being built in the main valley.

Evidence adverse to this suggestion must be summarized under several heads:

i) If deposited by glacial waters, the terrace should decline westward more rapidly than the present river, unless the western end had been raised by postglacial tilting. But, judging from the tilting of the glacial beaches of the Great Lakes, this latter possibility is unlikely.

ii) If deposited by glacial waters the material should be noticeably coarser at the eastern end grading to fine at the west. This is not the case.

iii) There are three conspicuous examples of small valleys containing only the low terrace, west of the farthest ice advance (just west of Black Earth, south of Arena, and west of Avoca), while there are but two such cases among the valleys heading in the terminal moraine, as previously cited. It would seem that the mere fact that two of the four valleys east of Mazomanie do not have the high terrace is not conclusive one way or the other. In fact, it would be just as plausible to suppose that there was but one Wisconsin advance in this region and that, since the longer valleys drained the ice both earlier and later than did the shorter ones, they received more outwash, and so were more aggraded. The thin terminal moraine crossing the valleys means a short stay of the ice-edge at this place, or poverty of débris in the glacier.

iv) No evidence was seen of weathering of the stratified drift underlying the till of the terminal moraine, as would be expected somewhere in the region if it were early Wisconsin and the till were late Wisconsin, since this interglacial interval is considered by many to be fairly long. The stratified drift may as well be outwash deposited by waters which flowed out in advance of the oncoming ice.

v) The evidence from the larger amount of leaching of the outwash plain, suggested by Alden and Weidman,[1] as showing that

[1] W. C. Alden, *op. cit.*, p. 192.

the high terrace is older than the terminal moraine and outwash of the low terrace, was not verified. For cuts on and directly west of the moraine show about the same amount of leaching as do the exposures farther west on the high fill.

vi) The high terrace marks a time of great filling, while the low one is much less important in this respect. Evidence from other regions has led to the generalization that the ice of the late Wisconsin substage was the most energetic of all the ice advances, building higher and more rugged moraines; eroding more deeply and more conspicuously; dumping more sediment into the drainage lines leading away from the ice-front, and so building larger valley trains. This line of evidence would point rather to the late Wisconsin than the early Wisconsin substage as the builder of the high terrace.

vii) Since erratics in Honey Creek Valley rest only on the high Wisconsin terrace, it seems clear that a glacial lake stood in this valley during at least part of the time when the slack-water fill of which these terraces are remnants was being deposited. It would be inferred that the lake was dammed during the maximum extent of the ice, rather than when the ice-edge stood farther east, as it did in early Wisconsin time if the early Wisconsin ice affected this immediate region. This piece of evidence suggests that the high Wisconsin fill in Honey Creek Valley was deposited when the ice-front stood at least as far west as Prairie du Sac.

The weight of this evidence is seriously against the possibility that the low terrace was deposited as a valley train of the late Wisconsin invasion.

b) When the ice-front of the Green Bay lobe had withdrawn east of the Portage divide, the ice-dammed lake, Jean Nicolet,[1] was formed with its outlet down the Wisconsin Valley. These outlet waters were clear, and probably cut the upper part of the valley train down to the level of the low terrace. Evidence that the low terrace was cut by waters from Lake Jean Nicolet follows.

i) The uniform height, 12 to 15 feet, of the terrace above the flood-plain all the way from the terminal moraine to the mouth of the valley, suggests strongly an erosional rather than a depositional origin.

[1] W. Upham, *Amer. Geologist*, Vol. XXXII (1903), p. 330.

ii) The material, in at least the upper few feet of the terrace, throughout the length of the valley is uniform in size, shape, and structure. The river having a uniform gradient would handle sediment of uniform size through its whole length. This would result in the coarser material in the eastern part of the high terrace, when cut by these outlet waters, being buried below several feet of finer re-worked material covering the low terrace.

iii) Its similarity to the Brule–St. Croix outlet of Lake Duluth is noticeable. This latter is also a broad sandy plain with dunes and blowholes upon its surface.[1]

iv) The low gradient, 1.75 feet per mile, for so large a volume of water, would favor a wide rather than a deep cut.

Against this mode of origin the following points may be registered:

i) It would be expected that the upper few feet of the terrace would be re-worked by the running water and the material therefor assorted. But this is, as a rule, not the case, for the pebbles are scattered indiscriminately through the sand.

ii) Weidman states, in relation to the Brule–St. Croix outlet that ". . . . Aside from cutting down a few drift dams that lay across the outlet, there was not much erosion."[2] It is possible, then, that there was not enough cutting by the waters of Lake Jean Nicolet to cut the upper terrace to the level of the lower one. However, the rapidity of cutting, depending upon the volume and the velocity of the river as well as the kind of material cut, may not have been the same in the two cases. So the slight amount of cutting of the Brule–St. Croix outlet would not carry a necessary implication against great cutting in the Wisconsin Valley.

iii) The relation of the terraces in the four tributary valleys just east of Mazomanie, previously discussed, is significant but not conclusive.

From the weight of this evidence, the low terrace appears to be a degradational level cut by waters from the glacial lake.

c) A third suggestion presents itself which combines the first and second in such a way as to obviate many of the difficulties

[1] Moses Strong, *Geology of Wisconsin*, Vol. III (1880), p. 387.

[2] Samuel Weidman, personal communication.

inhering in each. With the advance of the early Wisconsin stage, the outwash valley train was deposited. During the subsequent period of ice withdrawal, the pounded waters of the Fox River Valley flowed across the Portage divide and down the Wisconsin Valley, cutting away a large part of the valley train. This period must have been rather long, or erosion excessively rapid by a large and powerful river, for more erosion took place then than has taken place since the last withdrawal of the ice. This would not appear to be improbable, for, during this partial withdrawal, the ice may have dammed the lake for a much longer period of time than it did in the final deglaciation. Then when the late Wisconsin ice advanced to the region of Prairie du Sac, the outwash partially filled the channel cut below the early fill. Later, as the ice withdrew, the lake was again dammed east of the Portage divide and the waters flowed westward down the Wisconsin Valley, cutting the lower fill to the level of the low terrace. This would involve less cutting at any one stage than the first suggestion, and at the same time would allow the terrace to stand, as it does, at a constant elevation above the present river level, for the waters from the lake probably would cut to the same gradient as do those of the present Wisconsin River.

While the hypothesis of two Wisconsin advances will explain the presence of the high terrace in two of the valleys east of Mazomanie and its absence from the other two, it will not account for the absence of this high terrace in the tributaries farther down the Wisconsin River. And since it is evident that the former case can be explained on the basis of one advance into this region, the idea of two ice invasions in Wisconsin time may be discarded as needless.

SUMMARY

The terraces of Wisconsin age may be best explained on the hypothesis that they are connected with one glacial advance—that of the late Wisconsin ice-sheet—and that the lower terrace was cut from the higher by waters issuing from Lake Jean Nicolet.

PART III. THE PLEISTOCENE HISTORY

The first glacial invasion in Pleistocene time advanced on the eastern side of the region to a position somewhat east of the Wiscon-

sin terminal moraine. The eastern end of the region at this time stood relatively higher than it does now, so that the glacial waters flowing down the Wisconsin Valley had a steep gradient and transported coarse débris. The glacial drainage from at least a hundred miles of ice-front to the north must have flowed southward to the vicinity of Portage, and then westward down the Wisconsin River. In its course, along the ice margin, the river must have cut against the edge of the ice, at least in places, and must have broken off blocks of débris-laden ice, floating them into the Wisconsin Valley. Here many of them must have grounded and, upon melting, have deposited their loads. The adequate source of bergs, the abundant supply of glacial material, and the swift and powerful glacial river seem sufficient to account for the older drift deposited on the terraces of the mid-course of the valley. After the ice had stood long enough to build a valley train to a height of at least 75 feet above the present flood-plain in the mid-course of the valley, it withdrew and erosion cut away the valley train till all that remained were the terrace remnants on rock benches along the sides of the valley. It is not known how deeply this erosion progressed, but probably the valley was largely re-excavated.

At some time after this first valley train was built and before the next glacial advance, the eastern end of the region was depressed relative to the western end. A depression of 150 to 250 feet would not have been unlikely and would account for the phenomena observed.

The Kansan ice advanced across Iowa, crossed the Mississippi River in the neighborhood of Prairie du Chien, and projected a tongue of ice into the lower end of the Wisconsin Valley. The Mississippi was dammed, diverted into the Wisconsin Valley, and flowed eastward, carrying with it not only great quantities of coarse and fine outwash material, but abundant icebergs broken from the ice-front farther north as it encroached upon the Mississippi Valley. An eastward sloping valley train of coarse material was built. When the ice withdrew, erosion cut away the moraine and valley train, save where remnants are left on rock benches at Bridgeport and Wauzeka. The depth of this erosion is not known accurately,

but the valley was probably again re-excavated to about its maximum depth.

There are no terraces in the valley which correspond in age to the Illinoian drift found at the eastern end of the region, so the assumption is that the outwash from this glacial advance did not fill the valley high enough to be above the present surface of the river. The evidence of five well records[1] shows that at one time the valley floor stood, in the main and also the tributary valleys, 30 to 50 feet below its present level long enough to accumulate a bed of peat. It is probable that the outwash from the Illinoian invasion filled the valley only to this level, 30 to 50 feet below the present surface. Then ensued a period during which the vegetation accumulated on the swampy surface of this outwash.

During the Iowan epoch loess was blown on to the western part of the area, burying the drift with a blanket of eolian material.

In Wisconsin time not only the moraine at Prairie du Sac, but the valley train in the Wisconsin Valley, was deposited. As the ice withdrew east of the divide near Portage, ponding produced a lake which drained westward down the drift-filled Wisconsin Valley. This was for a time the main drainage for at least a hundred miles of ice-front lying toward the north, consequently a large quantity of clear water flowed down the valley. The upper part of the fill was largely cut away, leaving remnants which now constitute the upper terrace in the Wisconsin Valley. The down-cutting river reached grade at the level of the top of the lower terrace.

After the ice had withdrawn and the glacial lake was drained, the postglacial Wisconsin River cut away large parts of the lower terrace to form its present flood-plain.

[1] Well records which show peat 30 to 50 feet below the surface; fair grounds at Richland Center; schoolhouse 1½ miles northeast Richland Center; Bear Creek ¾ mile north of junction with Little Bear Creek; Little Bear Creek ½ mile north of junction with Bear Creek ¼ mile southwest of Leland.

ORIGIN OF THE TRIASSIC TROUGH OF CONNECTICUT

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The paper by Professor W. M. Davis on "The Triassic Formation of Connecticut"[1] has long been regarded as a masterpiece in geologic literature. So well was the work done that little has been added to the knowledge of the Newark formation in Connecticut since its publication. Professor Davis did not, however, reach a definite conclusion concerning the origin of the trough within which the Newark sediments collected. Two hypotheses have been most widely held to explain the origin of the depression. It is the purpose of this paper to state briefly the field facts which bear upon these hypotheses and to suggest a method of research which may aid in the solution of the problem.

The two hypotheses referred to are: (1) the depression was formed by a gradual bending downward of a canoe-shaped trough without faulting movements (Fig. 1), and (2) the depression was developed by faulting movements on each side of the depression sedimentation (Fig. 2). Both of these hypotheses were suggested by Professor Davis in his report.[2] The fundamental hypothesis may be modified by certain limiting conditions. Professor Davis was inclined to believe that the formation of the trough was not accompanied by faulting. He also held that the original area covered by the Newark deposit was not much greater than that over which the series outcrops today.[3] Professor Grabau, while agreeing with Professor Davis in part, believes that a vast geosynclinal wedge extended from the eastern folds of the Old Appalachian Mountains, and that the present areas "are mere erosion remnants

[1] *Eighteenth Annual Report, U.S. Geol. Surv.* (1897), Part II, pp. 1–192.

[2] *Ibid.*, pp. 37–38. [3] *Ibid.*, p. 191.

of once much more extensive deposits . . . . preserved by being faulted beneath the level of erosion."[1]

Again, Professor Davis suggests that the trough may have been developed by faulting movements on each side of the depression (Fig. 2), whereas Professor Barrell[2] has limited the faulting to the eastern border (Fig. 3).

It is believed that there is general agreement with Professor Davis' statement that the "ancient mountains of Western Upland must

FIG. 1.—Diagram representing a depression formed by a gradual bending downward of a canoe-shaped trough, without faulting.

FIG. 2.—Diagram representing a depression developed by faulting which was continuous during the period of sedimentation.

have been worn down to a peneplain, or at least reduced to hills of moderate elevation and gentle slope, at the time the accumulation of the sandstones began."[3] It is further agreed that "the basement on which the Triassic strata rest" was worn "so low that no great additional amount of waste could be worn from it" had there not been depression of a central area accompanied by "correlated elevation of the adjoining areas on the west and east."[4]

Professor Davis goes on to say that "two suppositions may be made as to the character of these correlated elevations. The

[1] A. W. Grabau, *Text Book of Geology*, Vol. II, pp. 612–13.

[2] Joseph Barrell, "Central Connecticut in the Geologic Past," *Bulletin No. 23, Conn. State Geol. and Nat. Hist. Survey.*

[3] *Eighteenth Annual Report, U.S. Geol. Surv.*, Vol. II, p. 25.

[4] *Ibid.*, pp. 37–38.

trough may have been bent down between two arched areas on either side, as in Figure 1, or the trough may have been faulted down between two uplifted blocks alongside of it, as in Figure 2. While it did not seem advisable to make a final choice between the alternatives, the conditions illustrated by Figure 1 were favored, chiefly because the centripetal dips there shown would give, after general eastward tilting with more or less faulting, moderate dips for the lower strata in the east and stronger dips for the same strata in the

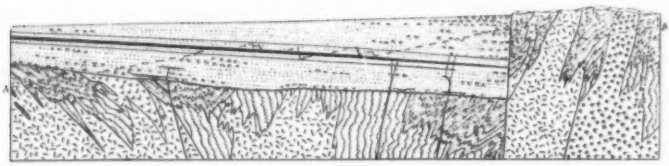


FIG. 3.—(After Barrell)

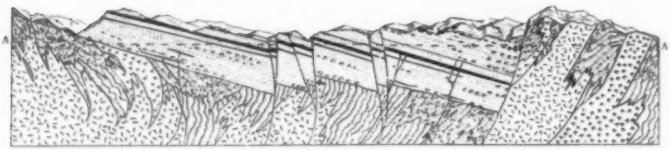
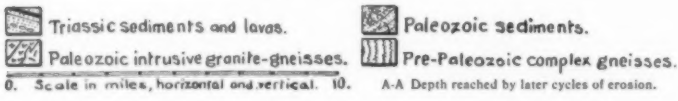


FIG. 4.—(After Barrell)


Triassic sediments and lavas.
Paleozoic sediments.
Paleozoic intrusive granite-gneisses.
Pre-Paleozoic complex gneisses.
0. Scale in miles, horizontal and vertical. 10.
A-A Depth reached by later cycles of erosion.

west. Professor Davis states that the field evidence showed an average dip to the east for the basal beds of 20° to 30° along the western border, and seldom more than 20° to the east for the analogous beds where exposed along the eastern.[1] His section, so widely copied in textbooks (Fig. 5), is therefore based on Fig. 1.

Professor Barrell, in his well-known study of "Central Connecticut in the Geologic Past," gives his conception of the origin of the depression. His idea is illustrated by Figures 3 and 4. A marginal fault of gradual development along the east side of the Connecticut

[1] *Eighteenth Annual Report, U.S. Geol. Surv.*, Vol. II, p. 39.

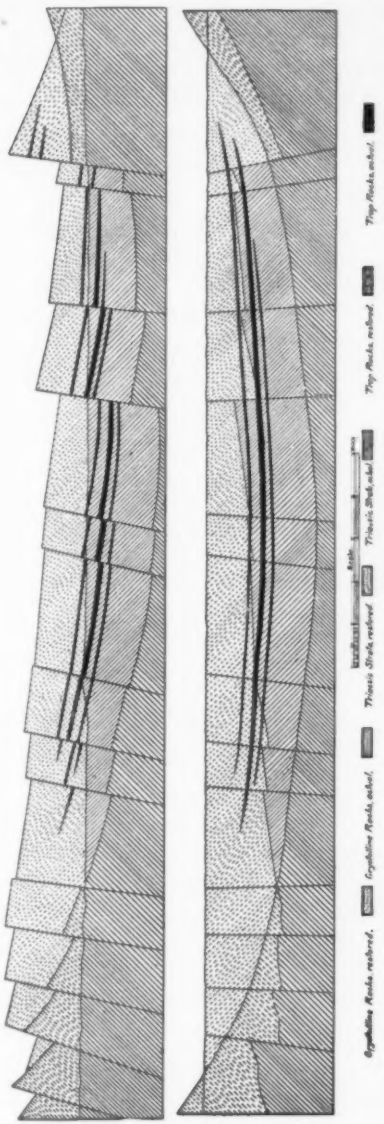


FIG. 5.—Sections across the Connecticut Valley Triassic. The upper section shows the present attitude of the formation as tilted and faulted. The parts which have been removed by erosion are restored. The lower section shows the supposed attitude of the formation before the tilting and faulting. (The shading with parallel lines does not represent planes of stratification.) From *Bulletin No. 6, Connecticut State Geological and Natural History Survey*, after Davis' figure in *Eighteenth Annual Report of U.S. Geological Survey.*

depression tilted the accumulating sediments toward the east and quickened the streams. Later smaller faults broke the trap flows and initiated the present topography (Fig. 4).[1] Professor Barrell supported his conception by the one statement that "the dominant segregation of conglomerates near the eastern margin is even more marked in the beds above the lava flows than in those below, and this greater average coarseness of the upper sediments indicates the intermittent regrowth of the mountains whose perennial waste kept supplying material for the basin."[2]

For reasons which will now be briefly stated the writer believes that Barrell's diagram represents most accurately the structure of the Connecticut depression during the Triassic.

1. A warping movement that distorts a peneplain surface without faulting must proceed very slowly. It is difficult to imagine that such a movement would revive the streams flowing into the Connecticut basin and cause them to transport bowlders of such a size as may be found not only in the edge but also toward the center of the trough. Cobbles 6 or 8 inches in diameter are found near the center of the valley, north of Meriden.[3]

2. Arkoses are common along the western border of the basin but are almost lacking along the eastern border, whereas coarse conglomerates are common along the eastern border but are seldom found along the western border. The inference is that the streams from the west were carrying the exfoliation products of a desert topography, but those from the east were carrying bowlders snatched from the wall of a growing fault scarp.

3. A consideration of the geometry of the geosynclinal hypothesis of Davis and the fault-monoclinal hypothesis of Barrell leads to conclusions which are more favorable to the latter. In Figures 6 and 7, let *W* represent the width of the Connecticut Valley. In northern Connecticut this width is approximately 21 miles; at Middletown it is 17 miles, or, if the Pomperaug Valley area is included within the larger basin, the width becomes 33 miles. Let *D* represent the depth of sedimentation within the basin. Compe-

[1] *Bulletin No. 23, Conn. State Geol. and Nat. Hist. Survey*, p. 28.

[2] *Ibid.*, p 29.

[3] *Eighteenth Annual Report, U.S. Geol. Surv.*, Part II, p. 33.

tent opinion places this thickness between 12,000 and 13,000 feet or between $2\frac{1}{4}$ and $2\frac{1}{2}$ miles. Let α represent the angle of dip developed in the basal beds by the gradual depression of the trough. At the sides of the geosnycline the actual angle would be greater than that indicated whereas, at the center, the beds would be flat, since the basin would be concave (Fig. 5). In either Case I (Fig. 6) or Case II (Fig. 7) it should be noted that the beds laid down at

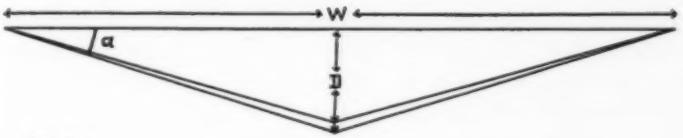


FIG. 6.—

Width	Depth	α
17	$2\frac{1}{4}$	$14\frac{1}{2}$
17	$2\frac{1}{2}$	$16\frac{1}{2}$
21	$2\frac{1}{4}$	12
21	$2\frac{1}{2}$	$13\frac{1}{2}$
33	$2\frac{1}{4}$	$7\frac{1}{2}$
33	$2\frac{1}{2}$	$8\frac{1}{2}$

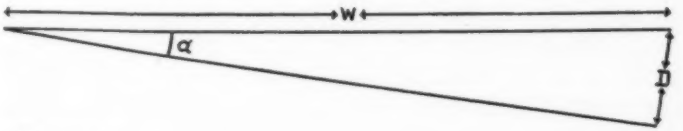


FIG. 7.—

Width	Depth	α
17	$2\frac{1}{4}$	$7\frac{1}{2}$
17	$2\frac{1}{2}$	$8\frac{1}{2}$
21	$2\frac{1}{4}$	$6\frac{1}{2}$
21	$2\frac{1}{2}$	7

the close of the period of sedimentation were approxiamtely horizontal, a fact overlooked by some writers. The diagrams are drawn to scale for a width of 17 miles and depths of $2\frac{1}{4}$ and $2\frac{1}{2}$ miles, respectively.

Whether the geosynclinal or the fault-monoclinal hypothesis be accepted, the present dips of the sediments of the basin were produced at the time of the post-Triassic faulting movements which tilted the rocks to the east. It would be advantageous to compare

the dips of the beds at the same horizon on the two sides of the trough, but only basal beds are exposed on the western side of the valley and upper beds on the eastern side. It is, however, possible to compare the known dips of the upper beds to the east with the dips of the basal beds to the west. Allowing for an erosion of 500 feet, the beds at the eastern side of the valley cannot lie far below the top of the series. Their original attitude at the close of the Triassic sedimentation was approximately horizontal. In the case of the geosynclinal hypothesis there may have been a slight dip to the west; in the case of the fault-monoclinal hypothesis, possibly a slight dip to the east. At present they have an average dip of 15° to 20° to the east. It is difficult to believe that the post-Triassic tilting was very dissimilar on the two sides of the valley. If it is assumed that the present dip of the upper beds was developed entirely at the time of the post-Triassic faulting, and that the tilt was, therefore, approximately 20° to the east, then, by adding 20° to the angle *a*, the present angle of dip of the basal beds at the western side of the valley should be obtained. Davis (see above) states that the average dip of the basal beds on the western side of the valley is 20° to 30°. In Case I (Fig. 6) by the foregoing method, the dips should be from 30° to 40°. In Case II (Fig. 7), angles from 20° to 30° are to be expected. It is true that, if the Pomperaug Valley area is included within the main basin, the results are inconclusive, but few authorities believe the original basin was much larger than it is today.

Assuming that the present dip of the upper beds of the Newark series at the eastern side of the valley represents the approximate angle of tilt to the east developed at the time of the post-Triassic faulting, then referring to Davis' diagram (Fig. 5), and conceiving that the present width of the valley was its approximate width in the Triassic period, in Case I the present dips should vary only slightly from the east toward the center of the valley, averaging perhaps a little lower about midway between the two points, but they should rise to a maximum at the western border. No normal dips near the center should be greater than the dips at the eastern border. In Case II there should be a progressive increase in dip

from the eastern to the western side of the valley.[1] The data concerning the strikes and dips within the Connecticut trough have never been assembled. Professor Davis' general statement quoted above would lead one to suppose, however, that there is an increase in the dips from the eastern toward the western side of the depression.

4. Pebbles in the upper conglomerates at the eastern border of the basin are known to be similar to rocks exposed at the very edge of the eastern upland. This condition is especially true near Lake Quonnipaug in Durham, Connecticut. East of the lake a chlorite schist, which is not common within the metamorphic rocks of the upland, outcrops for a mile or two. West of the lake the coarse "fan-glomerates" are filled with pebbles of this rock. The evidence indicates that the eastern limit of the Newark formation is at its ancient boundary, as Barrell's hypothesis would postulate, and that the basin sediments never extended over the eastern upland. If the eastern and marginal fault developed after the period of sedimentation, the chlorite schist at Lake Quonnipaug could not have been exposed to erosion at the time the "fan-glomerates" were being deposited.

5. The abundant development of those rocks so aptly named "fan-glomerates" by the western geologists along the eastern side of the basin is, in itself, strong evidence of the early initiation of faulting movements along this boundary. Such conglomerates are common throughout the exposed thickness of the Totoket block, but are not known on the western side of the valley.[2]

6. Finally, there is good evidence of the localization of vulcanism along the eastern fault line long before the end of the period of deposition within the basin. The writer has recently discovered a volcanic neck, in the southern part of Durham, north of Totoket Mountain, which lies within a stone's throw of the eastern fault margin.

[1] Excessive dips to the east are known near the eastern boundary fault. They are in the opposite direction from the drag dips which one would expect in this vicinity and have not been explained.

[2] Cf. C. R. Longwell, *Amer. Jour. Sci.*, IV (1922), 234–35.

For the reasons stated, the writer conceives of the Triassic basins of eastern Canada and the United States as a series of troughs of the basin range type which were developed during the collapse of the ancient land of Appalachia after the Appalachian mountain-building episode.

The Vale of Eden at the western base of the Pennine escarpment in northern England offers an interesting parallel to the inferred structure of the Connecticut Valley. Kendall has described the geology of the vale as follows:

> The succession in the Vale of Eden is of particular interest from the evidence that it furnishes of the physical conditions of the period and their changes. The valley is bounded on the east by the Pennine escarpment which owes its existence to a tremendous series of faults truncating the Permian and later rocks. The succession from west to east is: Carboniferous Limestone and Millstone Grit, covered unconformably by massive calcareous conglomerates, "Lower Brockram," usually dolomitized; bright red Penrith Sandstone about 300 m. (1,000 ft.); "Upper Brockram" interbedded in the upper part of the Penrith sandstone; Hilton Plant Beds with *Noeggerathia*, 45 m. (150 ft.); Magnesian Limestone 0–6 m. (0–20 ft.); Marls with gypsum having, locally, a basal conglomerate, 90 m. (300 ft.); St. Bees Sandstone (Trias) 600 m. (200 ft.)
>
> . . . . . .
>
> The materials of the Lower and Upper Brockrams respectively furnish evidence of contemporaneous movement of the adjacent fault zone. The Lower Brockram consists exclusively of fragments of Carboniferous Limestone and the writer (Kendall) infers that it represents gravel-fans washed by torrential rains from the uplifted fault country, when the displacements had exposed only that division of the Carboniferous series. The Upper Brockrams were laid down after the deposition of 300 m. (1,000 ft.) of Penrith Sandstone, which should have covered up an equivalent portion of the faulted area, yet these Brockrams consist in large measure of the Basement Conglomerate of the Carboniferous series, with occasional pebbles of the underlying Ordovician rocks. This is interpreted to mean that between the formation of the two Brockrams a great further movement of the faults took place bringing the base of the Carboniferous up within the action of surface erosion.[1]

The eastern upland of Connecticut consists of such a tangle of metamorphic rocks that the rock succession is difficult to interpret.

[1] "The British Isles," *Handbuch der Regionalen Geologie*, Band III, Abteilung 1, p. 188. The writer is indebted to Professor Fearnsides, of Sheffield University, for calling his attention to the parallelism here described. "Brockram" is a local term used in the Vale of Eden for the rock known to the western geologists as a "fanglomerate."

However, the description of the geology of the Vale of Eden suggests a possible problem in sedimentation. A detailed study of the rocks of the eastern upland near the fault zone, combined with a microscopic study of the Anterior, Posterior, and Upper sandstones of the Connecticut Valley deposits might yield further evidence of the progressive growth of the eastern fault during the period of sedimentation.

IN SUPPORT OF GARDNER'S THEORY OF THE ORIGIN OF CERTAIN CONCRETIONS[1]

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New Concord, Ohio

In an article in the *Journal of Geology*, Gardner[2] has maintained that certain concretions are formed in supersaturated or overloaded water carrying fine clay particles. He believes that the particles are pressed together and are gathered in lumps just as the finely disseminated particles of butter are gathered together in churning and that these particles grow by accretion and gain their spherical form by being rolled along the bottom. He bases his opinion on observations of aggregations of mud balls in the bed of a stream after a flood in the Rio Chaco region of the San Juan Basin, New Mexico.

In the summer of 1921 the writer observed similar phenomena in the bed of the North Fork of the Red River, Beckham County, Oklahoma. As a result of a series of severe rains, this river, which is usually an insignificant stream flowing in sand-choked channels, had been flowing bank full. After the flood had subsided the writer observed on one of the sandy flats in the river bed a remarkable collection of clay aggregations similar to those described by Gardner. They consisted both of clay balls and cylinders, the former being much more numerous. The balls varied from less than an inch to about six inches in diameter. The cylinders were from four to six inches in diameter and a foot or more in length. Both balls and cylinders were composed of fine clay, with a small amount of sand and gravel in them or imbedded in the outer portion. The cylinders were apparently the result of two balls becoming stuck together and being rolled along the bottom, as several cases were observed showing the steps in this process. The considerable

[1] Published by permission of the Director of the Oklahoma Geological Survey.

[2] J. H. Gardner, "Physical Origin of Certain Concretions," *Jour. Geol.*, Vol. XVI (1908), pp. 442–58.

number of these aggregations at the place described seemed to be due to the fact that the flat was on the inside of a rather sharp bend where the current would be slackened.

FIG. 1.—Concretionary-like aggregations of fine clay deposited on a sandy flat in the bed of the North Fork of the Red River, Oklahoma, during a flood.

From the very perfect resemblance of these clay aggregations to ordinary concretions and the rather large number of them found after this one flood, the writer is inclined to agree with Gardner that this method of formation of concretions may be more common than is ordinarily supposed.

Figure 1 gives some idea of their size and distribution.

MUD CRACKS ON STEEPLY INCLINED SURFACES

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It is generally accepted that well-developed mud cracks or desiccation fissures are formed only on level surfaces that have been covered by shallow stands of water. Hence the presence of this phenomenon would be supposed to indicate level, low-lying mud flats; estuarine flood-plain, or playa in origin.

In the spring of 1922 it was my fortune to observe at Williamstown, Massachusetts, well-defined mud cracks in what I believe to be an atypical position. A small stream had undercut a bluff composed of finely laminated glacial-lake clays. Down the face of this bluff several mud streams had flowed, solidifying before reaching the brook. The surface of these mud streams was seamed with sun cracks which reached depths exceeding 8 inches, and whose intersections produced irregular polygons varying from 6 to 18 inches across. Clinometer readings carefully taken on those portions of the surface which exhibited the best-defined polygons ranged from 11° to 38°, with an average of about 22°. Some of the best polygons appeared on the steeper slopes.

Had any one of these mud flows been covered by later deposits and induration taken place, the presence of these sun-cracked polygons along the bedding-plane would have unquestionably been taken as evidence that it marked the contact between two horizontally deposited beds of clay. While the above-noted phenomena may not be at all unusual, it would seem that sufficient attention has not been called to occurrences of this type which might lead to serious stratigraphic errors after consolidation of the inclosing sediments.

Petrological Abstracts and Reviews

ALBERT JOHANNSEN

Schlossmacher, K. "Die Sericitgneise des rechtsrheinischen Taunus," *Jahrb. d. Preuss. Geol. Landesanst., f. 1917*, XXXVIII (1919), Th. 1, 374–433, pl. 1, figs. 2.

The sericite-gneisses of the Taunus are dynamo-metamorphosed quartz-keratophyres and felso-keratophyres. Ten chemical analyses are given, of which four are new. A general description and a discussion of the chemical relationships are followed by descriptions of the various localities.

Schlossmacher, K. "Ein Verfahren zur Herrichtung von schiefrigen und lockeren Gesteinen zum Dünnschleifen," *Centralbl. f. Min. Geol., etc.*, 1919. Pp. 190–92, fig. 1.

The usual method of boiling porous and schistose rock fragments in Canada balsam is not efficient. Here is described an apparatus by means of which the pore spaces in the rock may be filled with balsam. A tube with a stoppered side opening is partially filled with balsam, placed in a water bath, and the air exhausted. Any time thereafter chips to be sectioned are placed in the side tube, the air is exhausted, the tube is tilted so that the chip falls into the balsam where it is left until the bubbles cease.

Schlossmacher, K. "Keratophyre und ihre dynamometamorphen Äquivalente aus der Umgegend von Bad Homburg im Taunus," *Jahrb. d. Preuss. Geol. Landesanst. f. 1919*, XL (1920), Th. 1, 460–505.

The metamorphic rocks of the Taunus are keratophyres and soda-keratophyres; tuffs were nowhere found. Detailed petrographic descriptions and two new chemical analyses are given.

Schlossmacher, K. "Einige nichtmetamorphe paläovulkanische Eruptivgesteine aus dem Vordertaunus," *Zeitschr. d. Deutsch. Geol. Gesell.*, LXXII (1920), 25–27.

Unmetamorphosed paleovolcanic albite-trachytes and trachy-andesites, that is, keratophyres and keratophyre-porphyrites, are described from eight

localities. The phenocrysts are usually albite, in two occurrences orthoclase with intergrown albite; the groundmass is trachytic albite with small amounts of magnetite, chlorite, and a little sericite.

SCHNEIDERHÖHN, H. "Die Methoden zur mikroskopischen Untersuchung kristallisierter Körper," *Handbuch der mikroskopischen Technik*, Stuttgart, X (1914), 45–94, figs. 68.

Gives a brief but very good summary of petrographic-microscopic methods, well illustrated by figures. Attention is called to the fact that these methods are applicable not only to the determination of rocks, but that they may be used in the determination of natural and artificial salts, synthetic minerals, cement, etc.

SCHNEIDERHÖHN, HANS. "Über Methoden, um rasch und einfach aus Photographien Strichzeichnungen herzustellen," *Senckenbergiana*, I (1919), 190–93, figs. 2.

While this is not a petrographic article, the method here given for rapidly reproducing photographs may be of interest to petrographers, especially in these days of poor print-paper. A developing-paper print of the thin section or other petrographic subject is "inked-in" with waterproof ink. It is then immersed in subdued light for a few minutes in acid hypo, and then, without washing, placed in a rather concentrated solution of about equal parts copper sulphate and potassium bromide. In a few minutes the silver image will become altered to a yellowish image of silver bromide. When of a yellow color, it is washed for a few moments and re-immersed in the hypo until the yellow color disappears and leaves a white background. Without first immersing in hypo the operation is somewhat slower. Instead of copper sulphate, potassium ferricyanide may be used. A second method, less desirable on account of the poisonous nature of the material, but more rapid, is to dissolve the silver in a dilute solution of potassium cyanide. The print should be thoroughly washed afterward.

SCHNEIDERHÖHN, HANS. "Die mikroskopische Untersuchung undurchsichtiger Mineralien und Erze im auffallenden Licht und ihre Bedeutung für Mineralogie und Lagerstättenkunde," *Neues Jahrb.*, B. B. XLIII (1920), 400–438.

Here is a most excellent summary of work done on the determination of opaque minerals by means of incident light under the microscope. A long bibliography is given.

SCHNEIDERHÖHN, HANS. "Beiträge zur Kenntnis der Erzlagerstätten und der geologischen Verhältnisse des Otaviberglandes, Deutsch-Südwestafrika," *Abhandl. d. Senckenbergischen Naturf. Gesell.*, XXXVII (1921), 221–321. Figs. 16, figs. 40 in photogravure, and colored map 1.

The greater part of this report is economic and geologic. Only a few igneous rocks are mentioned, namely, aplite, olivine and mica kersantites, and microgranite. The aplite occurs in a dike-like mass widening into lens-shaped masses in several places. It is cut by the younger kersantite. The microgranite forms a laccolite intruded between strata of the dolomite, and in all probability was derived from the same source as the aplite which may represent the channels through which the larger mass was intruded.

SCHÜRMANN, H. M. E. "Beiträge zur Petrographie der östlichen arabischen Wüste Ägyptens," *Centralbl. f. Min., Geol., etc.*, 1921, 449–58, 481–90.

Very brief descriptions are given of the various igneous rocks of Gebel Mogul, between Gebel Mogul and Um Dalfa, and between Gebel Gharib, Gebel Dara, and Gebel Mogul. Neither chemical analyses nor modal percentages are given, though the various minerals are named. The rocks described are various granitites, pegmatitic granite, hornblende-syenite, and tonalite as plutonic rocks occurring in stocks; pneumatolytic granite, granite-pegmatite, quartz-diorite, and quartz-augite-diorite, plutonic rocks in dikes; pegmatite, graphic-granite, quartz, aplite, riebeckite-aplite, quartz-bostonite, malchite, minette, augite-kersantite, amphibole-vogesite, granite-porphyry, riebeckite-granite-porphyry, and quartz-diorite-porphyrite in dikes; and the following extrusive rocks, also in the form of dikes: granophrye, quartz-porphyry, riebeckite-quartz-porphyry, felsite-porphyry, various porphyrites, andesite, diabase-porphyrite, and diabase.

SCHUSTER, ERNST. "Calcitführende Auswürflinge aus dem Laacher Seegebiet," *Neues Jahrb.*, B. B. XLIII (1919), 295–318, pls. 2.

The calcite-rich ejected blocks of the Laacher Sea region which occur in the leucite-phonolite-tuff are alkali syenites which must have formed the country rock in the deeps. The calcite is regarded as a magmatic mineral, as is also cancrinite and the rare calcium apatite. The rocks may be called calcite-pegmatites and calcite-syenites. In other fragments melilite was developed as well as calcite.

SEDERHOLM, J. J. "On Synantetic Minerals and Related Phenomena. (Reaction Rims, Corona Minerals, Kelyphite, Myrmekite, etc.)," *Bull. Comm. Geol. Finlande*, No. 48, 1916. Pp. 148, pls. 8, figs. 14.

Synantetic minerals are those which are characteristic at the contact between two definite minerals in igneous rocks, kelyphite rims being one form. Myrmekite is applied to intergrowths of plagioclase and vermicular quartz. In this paper the various forms and the different minerals occurring are discussed in great detail, and the literature is fully summarized.

SHAND, S. J. "The Pseudotachylyte of Parijs," *Quart. Jour. Geol. Soc.*, LXXII (1917), 198–221, pls. 4, figs. 13.

In the granite from the neighborhood of Parijs, Orange Free State, there occur abundant veins and networks of a dense black rock, to which, from its resemblance to tachylite, the name pseudotachylite is given. Numerous sketch maps and two photographs show the nature of the occurrence in the field, and eight photogravures show the appearance as thin sections. The rock is very opaque, due to innumerable inclusions of very fine black specks of magnetite. In some of the widest veins there is less magnetite but many polygonal spherulites of dark-brown color in a felt of feldspar-microlites. Several analyses are given. The writer concludes that the pseudo-tachylyte originated from the granite itself through melting, which was caused, not by shearing, but by shock or gas-fluxing.

SHAND, S. J. "The Principle of Saturation in Petrography," *Geol. Mag.*, I (1914), 485–93; II (1915), 339–40.

Mr. Shand replies to certain critics of his system of classifying rocks on the basis of saturated or unsaturated minerals. (The former minerals are those which are stable in the presence of free silica under magmatic conditions, the latter those that are unstable.)

SHAND, S. J. "A System of Petrography," *Geol. Mag.*, IV (1917), 463–69.

Gives further ideas as to desirable features in a classification of rocks. Shand proposes the following factors: (1) degree of saturation, giving five divisions; (2) the double ratio of Or-Ab-An, giving about eight families within each division; (3) the color ratio, giving from two to ten, but preferably four groups in each family; (4) crystallinity, giving two sub-groups within each group; (5) ratios of specific minerals or groups of minerals, giving the types to which "specific" names will be attached; (6) trivial characters of mineralogy and texture, giving varieties.

SHAND, S. J. "The Norite of the Sierra Leone," *Geol. Mag.*, V (1918), 21–23.

Describes two norites from Sierra Leone. One an olivine-rich norite, belongs to 2312 (new form) of the reviewer's classification; the other melanocratic, and without olivine, belongs to 3312.

SHANNON, EARL V. "Petrography of Some Lamprophyric Dike Rocks of the Coeur d'Alene Mining District, Idaho," *Proc. U.S. Nat. Museum*, LVII (1920), 475–95, pls. 3.

The various dike-rocks from the Coeur d'Alene district, collected by Ransome, Calkins, and Umpleby, are here classified and described. Among the rocks are various minettes, spessartites, and vogesites, and one odinite. From the widespread occurrence of these dikes the conclusion is reached that the district is underlain by a granitic batholith which is so far down that none of the complementary aplite reached the surface. The dikes and ore veins belong to substantially the same period.

SKOETSCH, CARL. "Die Einschlüsse in den Basalten zwischen Godesberg und Remagen," *Centralbl. f. Min., etc.*, 1921, 353–63.

In this paper are described all the different minerals which have been found in inclusions in the basalts of this region, as well as their mode of origin, and the alterations produced in them by the basaltic magma.

SMITH, W. CAMPBELL. "Riebeckite-Rhyolite from Northern Kordofan, Sudan," *Mineralog. Mag.*, XIX (1920), 48–50.

Describes a riebeckite-rhyolite from which certain ancient stone implements found at Beraeis are made. Two specimens of tinguaitic dikes from Kadoro, described by Linck, represent the only previously mentioned soda-rich rocks in Kordofan.

SPANGENBERG, K. "Die Einbettungsmethode," *Fortschr. d. Min. Krist. u. Petr.*, VII (1920), 397–458.

Under "Immersion Methods" are included all those methods for determining refractive indices based upon certain appearances at the contact between a known and an unknown medium. Three groups are discussed: (1) Disappearance of the border, (2) Töpler's method of inclined illumination (often spoken of as Schroeder van der Kolk's method); (3) Becke's method of raising or lowering the tube of the microscope. A general summary is given of all methods, the reasons for the phenomena are discussed, the relative accuracy shown, and the cause of variation under different conditions pointed out.

SPANGENBERG, K. "Einige Anwendungen und Erweiterungen der Einbettungsmethode," *Centralbl. f. Min., etc.*, 1920, 352–62, 406–14.

Gives various applications of the immersion method.

STEIDTMANN, EDWARD. "Origin of Dolomite as Disclosed by Stains and Other Methods," *Bull. Geol. Soc. Amer.*, XXVIII (1917), 431–50, pls. 7.

Most dolomites were deposited in the sea. A minority were formed by the replacement of limestones by underground waters. Pure dolomites and limestones are far more abundant than mixed beds of limestone and dolomite. The occurrence of calcitic casts in dolomite, or of hollow casts bounded by perfect molds, indicate that the casts were deposited in dolomite. Dolomite rhombs, imbedded in a hornlike impervious mass of fine-grained marine calcite, were evidently formed in the ooze contemporaneously with the calcite.

TARR, W. A. "Oölites in Shale and Their Origin," *Bull. Geol. Soc. Amer.*, XXIX (1918), 587–600, pls. 2, figs. 2.

Describes certain oölites found in shale in the Wind River Mountains, near Lander, Wyoming. They are believed to be due to direct precipitation of colloidal silica by the electrolytic and saline character of the shallow waters into which they were introduced by streams from the adjacent land.

TARR, W. A. "Origin of the Chert in the Burlington Limestone," *Amer. Jour. Sci.*, XLIV (1917), 409–52, figs. 13.

Believes the widespread chert which occurs in the Burlington formation of Mississippian age has been formed from colloidal silica derived from inflowing streams and deposited by electrolytic action. The ellipsoidal form of the chert is attributed to the flattening of the colloidal mass under its own weight and later by the weight of overlying sediments.

TILLEY, C. E. "The Petrology of the Granitic Mass of Cape Willoughby, Kangaroo Island, Part I, *Trans. Roy. Soc. South Australia*, XLIII (1919), 316–41, pls. 2, sketch maps 2.

The granitic rocks of Cape Willoughby, Victor Harbor, and Port Elliot are thought to be chonolites connected below with a single batholith. They were intruded at the close of the orogenic movements in the region. The dominant rock is granite with minor intrusions of aplite and pegmatite. Interesting rocks are the albitites, quartz-albitites, and muscovite-albitites, which are regarded as the final differentiates from the residual magma. The first rock

consists essentially of albitite, with accessory apatite, zircon, and rutile, and with small amounts of muscovite and quartz. The albitite has the character of the "chequer" albite of Flett. The quartz-albitite is similar to the preceding but contains a blue opalescent quartz. The muscovite-albitite contains essential muscovite, some of which is regarded as primary, though some is secondary. The amounts of quartz and muscovite are not stated. The first and third rocks belong to 1112 (new form) of the reviewer's system, the second is 118 if the amount of quartz is over 5 per cent, as it presumably is since these rocks are contrasted with quartz-bearing albitites.

TILLEY, C. E. "The Occurrence and Origin of Certain Quartz-Tourmaline Nodules in the Granite of Cape Willoughby," *Trans. Roy. Soc. South Australia*, XLIII (1919), 156–65, pls. 2.

Certain nodules, consisting essentially of quartz and tourmaline, occurring in an aplite intrusive in granite, are considered as having developed by the replacement of albite and microcline by tourmaline. Says the writer: "Microscopic and other evidence tends to show that they are strictly penumatolytic products. In the slides is to be seen the very act of replacement of feldspar by tourmaline."

TSUBOI, SEITARŌ. "On the Determination of the Limiting Values of the Medium Refractive Index of a Finely Crushed Biaxial Crystal by the Immersion Method," *Jour. Geol. Soc. Tokyo*, XXV (1918), 38–41, fig. 1.

Maximum and minimum values of refractive indices are readily determinable but the intermediate value must be obtained from a carefully oriented section or be computed. In the latter case the angle between the c axis and one of the optic binormals must be known. In the present paper is given a method of determining limiting values for β, based on the fact that it must always lie between the two values observed in a crystal section of any orientation. By making observations on many grains, the difference between upper and lower limiting values may be made very small. Using basic plagioclase, the author made determinations to 0.003.

TSUBOI, SEITARŌ. "Notes on Miharaite," *Jour. Geol. Soc. Tokyo*, XXV (1918), 47–58, pls. 2.

The term *miharaite* is given to a lava from the volcano Mihara on the island of Oshima, Idzu. It is a basalt characterized by abundant phenocrysts of bytownite with a few of hypersthene and clino-hypersthene, and a very small amount of augite. The groundmass contains labradorite-bytownite microlites,

augite, magnetite, rare apatite, and negligible glass in the gray varieties, and plagioclase and augite in brown glass in the slaggy kinds. Five chemical analyses are given, all giving high SiO_2 (51.94, 51.13, 51.32, 51.40, and 51.45). The rock is given a new name on account of its occult quartz and normative bytownite. Mineral percentages are not given.

TSUBOI, SEITARO. "A Diagram for Determining Plagioclases." Published in the Japanese language in *Jour. Geol. Soc. Tokyo*, XXVII (1920).

Since cleavage pieces of plagioclase are used in determining their refractive indices, a table giving the values in (010) and (001) is of much greater value than the usual one giving α, β, and γ. These values, computed by Tsuboi and plotted as a curve, are reproduced in the reviewer's *Essentials in the Determination of Rock-forming Minerals and Rocks*.

TSUBOI, SEITARŌ. "On a Leucite-Rock, Vulsinitic Vicoite, from Utsuryoto Island in the Sea of Japan," *Jour. Geol. Soc. Tokyo*, XXVII (1920), 91–104.

Describes a porphyritic rock with abundant phenocrysts of sanidine and labradorite, the former slightly more abundant than the latter, less hornblende, augite, and titanaugite, and microphenocrysts of biotite, olivine, and apatite. The groundmass consists of laths of orthoclase and plagioclase and round leucites, with prisms and grains of aegirite-augite, some magnetite, and a trifle glass. An analysis is given which, recast into the norm, gives 4.63 per cent nephelite, 39.59 orthoclase, but no leucite. The analysis is readjusted to give leucite with the approximate proportions orthoclase 21.5, albite 42, anorthite 9, leucite 14, diopside 4.5, magnetite 2.8, ilmenite 1.2, apatite 1.1, olivine 2.7, and zircon 0.11. Compared with the description, however, this does not represent the actual mode (in which the plagioclase is stated to be labradorite), consequently it cannot be classified in the reviewer's system.

TSUBOI, SEITARŌ. "Volcano Oshima, Idzu," *Jour. Col. Sci., Tokyo*, XLIII (1920), art. 8. Pp. 148, 24 photomicrographs on 4 plates, map 1, plate profile 1, figs. 42.

Part of this report was published in the preliminary papers described in the second and third preceding articles. Here is given a geological and historical sketch of the volcano Oshima as well as descriptions of the rock types. These are basaltic bandaites, miharaites (which resemble the preceding but have no olivine), and basalt. Various analyses are given, and some beautiful photomicrographs.

A modification of Becke's method for determining $2V$, here given, greatly simplifies the process. The isogyre is first placed parallel to the horizontal cross-hair of the microscope, and the position of the melatope is determined by two angles, one measured in azimuth from the vertical cross-hair to the melatope by rotating the stage, the other measured from the center by means of a graduated eyepiece and any method similar to that employing a Schwarzmann's axial angle scale. The position of the melatope (A) is marked on a stereographic net and a great circle is drawn through it and the ends of the horizontal line. So far the method agrees with that of Becke. Change the conoscope into an orthoscope and rotate the stage until the section is at extinction and read the angle through which the stage was rotated. This locates one of the vibration directions which is now drawn at the proper angle in the projection. Locate, on the great circle previously drawn, the other melatope by means of an angle equal to that between the first melatope and the line representing the vibration direction. Measure $2V$ in the projection. In the older methods it was necessary to observe a second point on the isogyre, which was difficult. In the Tsuboi method only the position of the melatope is needed. Further, there is no need of using the refractive index in the new method. In Becke's original, five great circles were necessary, and in Wright's modification, four. In Tsuboi's, only one great circle is drawn, and one straight line.

TYRRELL, G. W. "A Contribution to the Petrography of Benguella, Based on a Rock Collection Made by Professor J. W. Gregory," *Trans. Roy. Soc. Edinburgh*, LI (1916), 537–59, pl. 1.

Benguella is one of three provinces of the Portuguese West African colony of Angola. Chemical analyses and complete descriptions are given of the rocks, which are granite, charnockite, dellenite, nephelite-sodalite-syenite, akerite, shonkinite, solvsbergite, ouachitite, and various basic intrusives. The two "charnockites" of Table I are 227′ (new form of reviewer's system) or monzotonalites (granodiorites in limited sense), while the type charnockite from India is 226′, or typical granite. The hornblende-hyperites belong to 3312, as they should. The granite of Table II is 216′, typical granite; the granodiorite is 227′, granodiorite in sense usually used but better monzo-tonalite. The two dellenites computed in Table IV are 227′ for the Angola rock, and 227″ for the one from Sweden. That is, the former is the extrusive equivalent of a granodiorite, while the latter is the extrusive equivalent of a quartz-monzonite. The shonkinite of Table V is 2113, which is not according to definition of shonkinite as originally give by Pirsson, for in that the dark constituent must form more than half the rock, consequently it must be in Class 3, as actually is the type Montana specimen given in the same table. The Angola rock falls into the group with pulaskites although the feldspathoid in the latter rock was given by Williams as nephelite or its decomposition product analcite.

TYRRELL, G. W. "Further Notes on the Petrography of South Georgia," *Geol. Mag.*, III (1916), 435–41.

Describes various rocks from South Georgia. The sediments are slates and phyllites, arkoses and grits. The igneous rocks are epidorite, dolerite, basalt, alaskite, quartz-felsite, lavas and tuffs of doubtful affinities, epidosite, and augitite. So far as petrographic evidence goes, the question whether South Georgia belongs to Suess' "Southern Antilles," or whether it is a remnant of an old sunken continental land remains unsettled.

TYRRELL, G. W. "The Petrography of Arran," *Geol. Mag.*, III (1916), 193–96.

Pitchstone xenoliths in a basalt dike throw some light upon the question of the temperature of lavas. The phenocrysts of quartz have suffered hardly at all, the andesine has had a softening on the margins and fissuring in the interiors, while the orthoclase shows fusion around the margins and along cleavages, producing a yellow or grayish glass, differing from that of the groundmass. The temperature of the intruding lava is therefore thought to have been between 1170° C. and 1375° C.

TYRRELL, G. W. "Some Tertiary Dykes of the Clyde Area," *Geol. Mag.*, IV (1917), 305–15, 350–56, figs. 3.

Describes a dike-rock consisting of phenocrysts of anorthite in a groundmass of labradorite, enstatite and augite, and much glass. The glass indicates orthoclase, silica, and albite. Chemically this rock approaches andesite, from which it differs in its more basic phenocrysts. It is here called *Cumbraite*. It differs from Thomas and Bailey's Inninmorite in containing enstatite as well as augite. While the name cumbraite is proposed by Tyrrell, he says: "Whether these terms should obtain a circulation outside the discussion of the British Tertiary petrographic province is a question beyond the scope of this paper. My own opinion is that they should not."

TYRRELL, G. W. "The Trachytic and Allied Rocks of the Clyde Carboniferous Lava-Plateaus," *Proc. Roy. Soc. Edinburgh*, XXXVI (1917), 288–99.

Among the lavas of the Scottish Carboniferous, true andesites and rhyolites are absent, trachyte and allied rocks are present in subordinate quantities, while basalts predominate. In this paper are brief descriptions of albite-bostonites, albite-trachytes, albite-keratophyres, bostonites, keratophyres, quartz-keratophyres, felsite, and phonolite. Ten analyses, one of bostonite previously unpublished, are given.

TYRRELL, G. W. "The Igneous Geology of the Cumbrae Islands, Firth of Clyde," *Trans. Geol. Soc. Glasgow*, XVI (1916–17), 244–74, figs. 5.

Most of the igneous rocks of the Cumbraes are of Lower Carboniferous age. They are predominatly basaltic and originally covered from 2,000 to 3,000 square miles.

TYRRELL, G. W. "The Picrite-Teschenite Sill of Lugar," *Quart. Jour. Geol. Soc.*, LXXII (1917), 84–131, pls. 2.

The Lugar sill in the west of Scotland is found to be made up of a complex of rocks belonging to the analcite series. It forms a mass 140 feet thick and was intruded into cold rocks, as shown by chilled contacts at top and bottom, giving a fine-grained teschenite for a thickness of 10 feet. Beyond the margins, both top and bottom, the rock passes into coarse teschenite. In the interior the sill is divided into at least three bands by some process of differentiation or by successive intrusions, giving first a band of ultra basic rock—picrite and peridotite of coarse texture—occupying the major part of the whole mass. The picrite forms the upper part of the ultrabasic stratum, the peridotite the lower. Above the picrite is a band about 10 to 15 feet thick of fine-grained, basic, nephelite rock of the theralite family. Overlying the picrite, in places, is a peculiar rock to which the name *lugarite* has previously been given. It appears to be intrusive in the picrite, for veins of similar material traverse the latter rock in various places. Three of the teschenites are 2319′ of the reviewer's system, and two are 3320, the difference being the absence of orthoclase and the predominance of the dark constituents in the latter. Two chemical analyses are given as well as five more calculated from Rosiwal measurements. Two lugarites are 2320. (A rock described as lugarite in *Geol. Mag.*, 1915, 363, is here called a lugarite-like rock. It is 2218′.) One chemical analysis and two calculated analyses from Rosiwal measurements are given. As for the cause of the differentiation, the author thinks that the hypothesis of sinking of heavy crystals is well attested in the Lugar magma as a whole, but that the differentiation took place prior to its emplacement. The material was injected in successive intrusions, the teschenite first in cold rocks and formed the fine teschenite borders. While still cooling, but probably already solid, the picrite was intruded along its center plane. Here differentiation took place mainly by the sinking of olivine-crystals. Later, while probably still partly liquid, it was intruded by a small mass of lugarite.

VELDE, LUISE. "Die silikatischen Einschlüsse im Basalte des Bühls bei Kassel," *Abhandl. d. Senckenberg. Naturf. Gesell.*, XXXVII (1920), 111–35, pls. 4.

The silicic inclusions in the Bühl basalt in many cases preserve the characteristics of the original rocks from which they were derived, namely, sandstones

and slates. The great majority of the rocks are strongly metamorphosed and in them have been developed sillimanite, corundum, spinel, magnesium-diopside, scapolite, cordierite, and plagioclase. In this work the various inclusions are petrographically described and several chemical analyses are given. The most abundant inclusions are quartz-sillimanite.

C. H. BEHRE, JR.

VOGT, J. H. L. "Die Sulfid-Silikat-Schmelzlösungen," *Norsk. Geologisk Tidsskrift*, IV (1917). Pp. 97, figs. 13, and several tables and analyses.

VOGT, J. H. L. *Die Sulfid-Silikat-Schmelzlösungen: Die Sulfidschmelzen und die Sulfid-Silikatschmelzen.* Christiania, 1919. Pp. 131, figs. 45, and numerous tables and analyses.

The first of these two papers is essentially a résumé, written in 1917, of extensive work on sulphide-silicate solutions, giving the results obtained to the date of its publication. The second paper presents in detail the data of the earlier one, and embraces additional facts gleaned through two more years of work on the same subject; it is more detailed than the earlier publication and will be reviewed here first. The reviewer believes that with such comprehensive work as this, adequate abstracts are impossible. He strongly advises a careful perusal by metalographers, economic geologists, geochemists, and physical chemists. He wishes to commend the completeness of these studies.

Previous experiments have shown that certain sulphides, such as Sb_2S_3, Bi_2S_3, and Ag_2S, have a lower melting point than even those silicates with the lowest melting points. Other sulphides, such as those of lead, copper (Cu_2S), and iron (FeS) and pyrrhotite, have melting points about like those of the least refractory silicates and slightly higher than some of the eutectic mixtures of silicates with low melting points. Other sulphides finally, such as those of zinc, manganese, barium, and calcium, have melting points markedly higher than those of the more common natural silicates. Under-cooled sulphide mixtures or solid solutions of sulphides (sulphide glasses) are unknown.

From a study of the latent heat of fusion it appears that the sulphides PbS, Ag_2S, Cu_2S, FeS are not highly polymerized. It is found, further, that Fe_3O_4 is only slightly soluble in melts of Cu_2S; this is corroborated by the crystallization sequence as observed in magmas, for magnetite (and ilmenite) crystallize very early indeed from a pyrrhotite- or pyrite-bearing magma. Silicates are soluble in FeS or Cu_2S melts to only a very minor degree.

After a study of the relations between the various sulphides and their eutectics, the writer demonstrates that a eutectic is also possible in solutions of calcium sulphide (or manganese sulphide) in various silicates, such as melilite

and olivine. For example, in sulphide-rich melts with melilite, much of the mass of sulphide crystallizes out before the corresponding spinel, and the remainder crystallizes synchronously with the spinel.

In a solution of calcium magnesium silicate, calcium sulphide in the amount of 2.3 per cent lowers the melting point about 50°. By calculating the molecular depression it is found that polymerization of the sulphides of calcium and manganese in silicate melts is essentially nil; in fact, in the silicate solutions an extensive electrolytic dissociation more probably takes place.

Somewhat similar results as to the presence of a eutectic in solutions of zinc, aluminum, and iron oxides are discussed. In a melt bearing zinc sulphide, zinc spinel, and melilite, the order of crystallization follows the order of naming, as above; if, however, olivine be present instead of melilite, and only a very little sulphide, the order of crystallization is spinel, olivine, and sulphide.

In other slags the presence of copper and its relation to chondri-like structures, and to iron sulphide-bearing silicate solutions were studied. An interesting feature is the concentric arrangement of iron sulphide inclusions in hexagonal plates of biotite. From these observations it is found that Cu_2S is wholly insoluble or at best only slightly soluble in silicate melts rich in iron sulphide—attributable possibly to the presence of a common ion. Various conclusions drawn in this part of the investigation are interesting not only to the geochemist, but to the metallurgist as well.

Some space is also devoted to the crystallization of apatite and ore—the so-called "telechemical" minerals—those only distantly related to the silicate minerals.

The foregoing facts may be gleaned from the publication of 1919. The paper of 1917 briefs most of these observations, and adds considerable material on the part of sulphides in eruptive magmas—an application of physical chemistry to systematic petrogenesis.

Pyrite appears to crystallize very early from magmas, and has a higher melting point than magnetite. Pyrite generally precedes pyrrhotite in the normal sequence of crystallization; it also precedes chalcopyrite, which generally follows magnetite when all three sulphides crystallize from a melt. As previously observed, magnetite is only very slightly soluble in pyrite-rich melts; hence iron oxides are rare or absent in such melts.

A study of the norite-type magmas leads to the conclusion that the predominant mineral generally crystallizes first; thus, in plagioclase-rich norite, plagioclase is automorphic; in olivine-plagioclase, plagioclase-rich rock, plagioclase; in olivine-rich olivine-plagioclase rocks, olivine is automorphic, and so on. The physical chemistry of the several systems normally present in a gabbro-norite magma is summarized, and the writer believes in a eutectic for rocks of the gabbro-norite group, this eutectic, however, being expressed by a line, rather than by a point.

The rather constant appearance of pyroxenites and peridotites in close association with nickel-pyrrhotitic deposits, as at Sudbury, is thought to be

indicative of a eutectic mixture. Various conclusions regarding the order of crystallization in such magmas are drawn from petrographic data. The crystallization temperature for the normal norites is calculated (estimated) to lie between 1200° and 1300° at an atmosphere's pressure. From norite magmas acid dikes are distinct differentiation products, hence very generally associated with nickel-bearing norite. Petrographically the writer seeks to establish in such basic rocks (of the picrite-norite series) the increase of the nickel content with increase in hypersthene or bronzite; all the nickel deposits associated with peridotite have an exceptionally high nickel content.

The sulphides in the norite masses are supposed to be precipitated from the melts with decreasing temperature and then to settle to the bottom; the small amount of sulphides remaining later crystallized with the silicates and was not wholly segregated.

This work has demonstrated: (1) that the origin of nickel-pyrrhotite deposits may be explained by the laws affecting a system liquid-liquid; (2) that the leucocratic acid pyritiferous dikes correspond to the end-product of crystallization in a noritic magma bearing a slight amount of free quartz; (3) that the numerous occurrences of a chalcopyrite-rich sulphide mixture in locally distributed veins, especially such as are limited to the border phases of the rock, depend upon the fact that the chalcopyrite was concentrated in the end magma through progressive solidification of the sulphide constituents.

REVIEWS

Description géométrique des Alpes Françaises, Annexe du Tome second. By P. HELBRONNER. Six panoramas dessinés et peints par l'auteur, 23 planches dans un carton in-folio. Paris: Gauthier-Villars, 1921.

Gauthiers-Villars of Paris have, in this portfolio, put on the market colored panoramas of the French Alps which for both accuracy and beauty excel anything which has hitherto been produced. These panoramas have been drawn and colored as aquarelles by Paul Helbronner upon the basis of a trigonometric survey which this accomplished map-maker, Alpinist, and artist has made. In the course of this work, he found it necessary to ascend with his instruments all the high and difficult peaks of the region. In all, the panoramas consist of twenty-three plates in color joined in six groups. The largest of the panoramas is a complete tour of the horizon from the summit of Mont Blanc and consists of thirteen plates making a picture 19 ft. 6 in. in length. Two others—Mont Blanc from the Mont-Maudit and Mont Blanc from the Col du Géant—consist each of three plates of the same size as the others. Under each of the panoramas is an outline-drawing from which each peak may be identified. The coloring of these remarkable panoramas is superb while faithful to nature, as will be testified to by anyone who has climbed in these regions. The publication of the portfolio marks an epoch in the history of reproduction in color. The panoramas are all well suited for framing.

W. H. HOBBS

Coal. By ELWOOD S. MOORE. New York: John Wiley & Sons, March, 1922.

This is primarily a volume for the mining student and the engineer who is in charge of coal-mining operations, but it should also be of interest to every geologist. It brings together the best of a varied literature and places it at the disposal of all in usable form.

Neither time nor space is wasted in the introductory chapter. From a brief history of the subject the author starts out energetically to discuss the megascopic and microscopic properties of coal and then passes naturally into a discussion of its chemical composition. The best and latest methods of sampling are given in sufficient detail to enable a man

to follow them satisfactorily. A similar statement might be made regarding the methods of chemical analyses and, in later chapters, on mining methods.

It is unfortunate that with all our classifications of coal none seem to meet with general approval. Probably the best is that adopted by the Twelfth International Congress of Geologists, and which was originally developed by D. B. Dowling of the Canadian Geological Survey. The author favors a classification based upon more than two factors as best meeting the requirements, but admits the inadequacy of those now in use.

The origin of coal, through the transformation of vegetal matter accumulated in swamps, is discussed in considerable detail. The amazing rapidity of the metamorphic processes in any such accumulation is illustrated by the pebbles of coal occurring within the Coal Measures and the alteration of the upper end of a mine prop which had been subjected to high pressure for thirty years, during which time it also felt the effects of the heat from a fire in an adjacent part of the mine. The upper part of the prop and the cap wedge had a jet black color, a bright glossy luster, and conchoidal fracture. Evidently the intensity of the other factors may compensate for the lack of a large portion of the time element usually regarded as essential in the formation of the higher grades of coal.

A chapter is devoted to the vegetation of the coal periods and deals chiefly with the extinct forms. The author then takes up the structural conditions existing in coal seams, the location and determination of thickness of beds, and the value of coal lands. The latest mining methods and the preparation of the coal and coal products for the market are given due consideration. Finally a summary of the geology of the coal fields and the coal resources of the world completes the volume.

The book is adequately illustrated by well-chosen cuts, maps, and photographs. The plan of the text is admirable and the author handles his subject with good clear English, which is free from useless repetition. This has made it possible for him to get a remarkable amount of information into a single volume. Considering its size and scope, it is certainly one of the best texts on coal that has been published.

C. R. S.

Structure in Paleozoic Bituminous Coals. By REINHARDT THIESSEN, United States Bureau of Mines, Bulletin 117, Washington, 1920. Pp. xiii+296. Pls. CLX.

An extensive historical review of previous studies of woody structure in coal is followed by a detailed description of the technique of the

author's investigation. A study of the origin of peat follows, which throws some light on the way in which coal was formed in Paleozoic times. The author's study of the structure of coal embodies the results of his examinations of a number of different Paleozoic coals. Particular attention is given to microscopic studies, many of which were made with a magnification of 1,000 diameters, approaching the limit of visibility.

The text is accompanied by 160 plates, many of which contain several illustrations,and a bibliography of publications on the composition of coal.

An enormous amount of valuable information on the composition of coal has been accumulated in this bulletin. Many side lights on plant life during the Paleozoic are brought out by the study of the spores and other morphological elements of the coal. Biologic factors like the origin of rootlets and the existence of fungi in Paleozoic times, are revealed.

There are a number of theories concerning the origin of coal, but we are yet unable to form a conclusive conception of this interesting geological process. Thiessen's paper supplies a great amount of information which brings us a step nearer to a satisfactory conception.

A. C. N.

Contact-metamorphic Tungsten Deposits in the United States. By FRANK L. HESS and ESPER S. LARSEN. United States Geological Survey, Bulletin 725-D, 1921.

Of the 5,000 tons of tungsten concentrates (reckoned as 60 per cent WO_3) produced in the United States in 1918, about 1,400 tons was in the form of scheelite ($CaWO_4$) from contact-metamorphic deposits. Most of these deposits are along the western side of the Great Basin in California and Nevada but there are scattered deposits near Great Salt Lake and in Arizona, New Mexico, and Oregon. Their development has been recent, the first of the type being discovered in 1908. During the European war most of them were active producers but by 1920 all had lapsed into idleness because of the severity of competition with imported concentrates and richer American ores, combined with the great depression in the steel industry.

The contact-metamorphic tungsten deposits are nearly all at or near the contact between quartzose igneous rocks, principally granodiorites, and limestones. In a number of districts the deposits are clustered about several small granite outcrops close together, which suggest the presence of a larger granite body beneath.

The silicate minerals are those usual in contact-metamorphic deposits, except that minerals carrying boron appear to be absent and magnetite and hematite are notably rare.

The eccentric distribution of the deposits along some igneous contacts is correlated with the presence or absence of fractures which could serve as channels for the metamorphosing solutions, but other eccentricities such as the presence of chunks of unaltered limestone in the intrusive are not readily explained. Where the intrusive rock is in contact with a large body of sediments the contact-metamorphic rocks may follow the contact rather regularly, or may replace certain beds in the sediments, or may follow fissures crossing them. Unlike many contact-metamorphic deposits which are notably compact, these commonly contain vugs some of which attain the dimensions of caves in which a man can stand upright. These are not the result of solvent action subsequent to metamorphism but were formed during metamorphism, and are characterized by crystals of quartz some of them a foot long projecting inward from their walls.

Contact metamorphism has usually affected the igneous rock as well as the limestones, but the metamorphic zone is much narrower in the intrusive than in the limestone and is much more siliceous being made up mostly of quartz with subordinate dark silicates of the same varieties that characterize the adjacent altered limestone. A distinct zoning is usually perceptible in the alteration of the limestone. The zone nearest the intrusive is characterized by dark-colored iron-bearing silicates—iron-bearing garnet, epidote, pyroxene, hornblende, etc., with calcite and quartz and minor amounts of other minerals. This zone is the chief host of the scheelite.

Beyond this zone comes a zone characterized by light-colored silicates poor in iron, tremolite and wallastonite being the commonest of these silicates. Colorless diopside, scapolite, colorless garnet, and other silicates are present in less abundance. Calcite is very abundant. Scheelite is absent. The zone of light-colored silicates grades outward into the marble that forms the outermost part of the contact-metamorphic aureole.

Evidences are present that in many of the deposits the minerals were not deposited contemporaneously, but that one mineral followed another in a regular sequence. The details of the successive replacements were not worked out microscopically, but in general it appears that garnet was one of the first to be deposited and that sulphides were among the last.

The authors propose the name "tactite" for the rocks and ores developed by contact metamorphism nearest the intrusive (Latin, *tactus*, "touch"). This term seems well chosen and may prove a convenience. It should be noted that the authors designate as "tactite" only the zone

of dark silicates next the intrusive, and do not apply the term to the zone of light-colored silicates or to the marble.

No evidence of enrichment through the action of meteoric waters was noted in any of the deposits. Leaching is shallow.

The average tenor of the deposits worked near Bishop, California, is about 0.5 per cent of WO_3; ore mined in the Mill City, Nevada, district averaged about 2 per cent of WO_3.

E. S. BASTIN

Geology of the Non-metallic Mineral Deposits Other Than Silicates. Vol. I. Principles of Salt Deposition. By A. W. GRABAU. First edition. New York: McGraw-Hill Book Co., 1920. Pp. xvi+435, figs. 125.

This volume is a treatise on applied stratigraphy. The author designates it as "a hand-book of salt-geology," using the term salt to include phosphates, nitrates, borates, and similar deposits, as well as common salt.

The author discusses first the sea as a source of saline deposits, basing a number of his conclusions on the careful work by Van't Hoff on the famous Stassfurt deposits. This is followed by a well-illustrated chapter concerning the conditions by which sea salts are deposited in nature, emphasis being placed on their organic deposition.

In the discussion of lagoonal deposits, it is concluded that many of the older salt deposits, generally believed to have been formed after the manner postulated by the bar theory, cannot be accounted for in this way, inasmuch as they are non-fossiliferous. Lagoonal deposits, such as those forming in the Karatugas Basin, contain fossils.

A chapter is devoted to the classification of terrestrial salts, and the larger portion of the book is devoted to a discussion of their origin, method of concentration, and distribution. Throughout the book numerous salt lakes and salt basins of various types are described, and their deposits discussed.

Attention is given to the mooted questions of the origin of nitrates, phosphates, and dolomites, and the several theories which have been advanced to explain them are stated.

In the chapter on "Deformation of the Salt Bodies," the author favors the view of Rogers that the salt domes of Louisiana and Texas are of exogenetic origin, but doubts whether all the characteristics of salt domes can be accounted for without the action of endogenetic forces.

The last chapter is devoted to an interesting discussion of the "Conditions of Salt Deposition in Former Geological Periods." In this chapter, and indeed throughout the book, attention is directed to the stratigraphic and paleontologic characteristics of the various types of deposits, the object being to prepare the reader for the stratigraphic chapters which are to follow in Volume II.

The book is a valuable contribution to the science of salt deposits, and should prove of great service to students of economic geology.

W. T. B.

Upper Cretaceous Floras of the Eastern Gulf Region in Tennessee, Mississippi, Alabama, and Georgia. By E. W. BERRY. United States Geological Survey, Professional Paper 112, Washington, 1919.

The bulk of the flora is from the Tuscaloosa formation, and this paper is devoted principally to its elucidation and is to be regarded as a preliminary report, because Professor Berry's work was of a reconnaissance nature. Later, when the abundant workable clays of the Tuscaloosa formation are developed for economic purposes, many new localities of fossil plants probably will be discovered and additional representatives of its flora. One hundred and fifty-one species, representing eighty-seven genera from the Tuscaloosa formation, are described. The three other subdivisions of the Upper Cretaceous, the Eutaw formation, the Selma chalk, and the Ripley formation, contributed but meagerly to Berry's collection.

In comparing the Tuscaloosa flora with the European Upper Cretaceous floras, Berry finds that eighteen identical species are found in the European Cenomanian, two in the Turonian, and four in the Senonian. Therefore, the evidence of the floras is overwhelmingly in favor of the pre-Senonian and pre-Montana age of the Tuscaloosa and allied floras. Thirty Tuscaloosa species are found in the Atane beds of Greenland, and ten in the Patoot beds of the same island. The book is amply illustrated with plates.

A. C. N.

The Mineralization of the Copper Shales. By F. BEYSCHLAG. Zeitschrift für praktische Geologie. January, 1921. Pp. 1–16.

In this article Dr. Beyschlag brings forward very cogent arguments in support of the view that the famous copper deposits of Mansfield, Germany, are not of sedimentary origin, but are younger than the rocks

which inclose them and where deposited by solutions from magmatic sources and later enriched through the agency of descending solutions.

The copper ores occur in three positions: First, in the highly bituminous and pyritic beds of the copper shale (*Kupferschiefer*); second, in the immediately underlying Zechstein conglomerate and the Weissliegende—the latter forming the upper, bleached portion of the Rotliegende; third, in "rucken" or veins cutting any or all of these Permian sediments.

The dominant metallic minerals in all three situations are chalcopyrite, bornite, and chalcocite. Minor components are pyrite, galena, niccolite, safflorite ($CoAs_2$), and some others. In the copper shale the ore is mainly the so-called "Speise," a fine dust of sandlike ore particles in the rock. Strings and thin plates of sulphides also occur usually parallel to the bedding but elsewhere cutting it at small angles or uniting to form networks of sulphides. Bean and kidney-shaped masses of sulphides also occur. The microscope shows clearly that these sulphides have developed by replacement of the shales. Nowhere are the sulphide masses rounded as might be expected if they were original components of a mechanical sediment. In the Zechstein conglomerate and Weissliegende the ore minerals characteristically form "sand ore" 1–3 cm. thick immediately beneath the copper shale. In the sand-ore spaces between the sand grains are occupied by chalcopyrite and more rarely bornite and chalcocite. Heavy impregnations grade into mere sprinklings of sulphides. In more clayey beds segregations and platelike masses of sulphides occur. The "rucken" or veins occupy faults of a few centimeters to 100 meters displacement cutting the sediments. Many of them are richly mineralized while others are lean or barren. The maximum mineralization of the veins is in the vicinity of the copper shale and frequently the ore is confined to that part of the vein between the displaced portions of the copper shale. Two generations of ore minerals are recognizable in the veins, the older generation with nickel and cobalt arsenides, calcite, molybdenite, and rarely pitchblende, and the younger generation with copper sulphides and barite.

If it is assumed that the ores in the copper shale and Zechstein were deposited on the sea bottom at the time these sediments were laid down, it is necessary to assume that copper-bearing solutions were contributed to the sea by streams from the land or by submarine springs. The land areas of that period contained no rocks which by weathering or otherwise can be supposed to have yielded copper-rich solutions. If submarine springs had been the source of copper-bearing solutions the ores

in the sediments should presumably have been less uniform over wide areas than is actually the case.

The author of the paper turns therefore to igneous sources for an explanation of the ores. He points out that the Permian intrusive rocks of Europe are very generally copper-bearing and attributes the primary deposition of copper in the Mansfield deposits to solutions coming from the same magmatic source that at an earlier period yielded the eruptive rocks that form part of the Rotliegende. Cupriferous mineralizing solutions, according to Beyschlag, ascended along the vein fractures and spread laterally through and beneath the copper shale depositing chalcopyrite in the sediments by the filling of pores and by replacement, the bitumen and pyrite in these beds being instrumental in the ore precipitation. They also deposited chalcopyrite, cobalt, and nickel arsenides, molybdenite and rarely pitchblende in the fault fractures.

The writer points out that mineralization in the copper shale and Zechstein is greatest where veins cutting these formations are numerous and close together.

Although Beyschlag does not emphasize particularly the genetic significance of primary mineral composition, to the reviewer the presence in the veins of cobalt and nickel arsenides, of molybdenite and of pitchblende is highly suggestive of a magmatic origin for the mineralizing solutions.

Of the primary ores developed by the processes just described only remnants now remain. Most of the primary ore minerals have been replaced by the rich copper minerals, bornite and chalcocite, through the agency, Professor Beyschlag believes, of descending meteoric waters—the familiar process of downward sulphide enrichment. As evidence of such enrichment, it is shown that much if not most of the bornite and chalcocite is a replacement of chalcopyrite and drawings are presented showing such replacements. Bornite is characteristically the first mineral to replace chalcopyrite; chalcocite then replaces bornite. Further, there is a marked falling off in the abundance of the rich copper minerals in depth.

Of fundamental importance is the conclusion that the ores in the sediments and in the veins were formed contemporaneously, a conclusion based mainly on the restriction of ore in the veins to the vicinity of the ore-bearing beds and conversely the greater development of ore in the beds where they are cut by numerous and close-spaced veins.

E. S. BASTIN

INDEX TO VOLUME XXX

PAGE

Adapting a Short-Bellows, Roll-Film Kodak for Detail Work in the Field. By Chester K. Wentworth 158

Age of the Domes and Anticlines in the Lost Soldier-Ferris District, Wyoming, The. By A. E. Fath 303

Allen, R. C., and Barrett, L. P. Contributions to the Pre-Cambrian Geology of Northern Michigan and Wisconsin. Review by. A. C. McF. 85

American Species of Orthophragmina and Lepidocyclina, The. By Joseph A. Cushman. Review by A. C. McF. 260

Ammonite Evolution, Aspects of Ontogeny in the Study of. By A. E. Trueman 140

Androscoggin River, Former Courses of the. By Irving B. Crosby . 232

Annotated Index of Minerals of Economic Value, to Accompany a Bibliography of Indian Geology and Physical Geography. An. Compiled by T. H. D. la Touche, M.A., F.G.S. Review by A. C. McF. 88

Apus in the Permian of Oklahoma, On the Occurrence of an. By Rudolf Ruedemann 311

Arber, E. A. Newell. The Earlier Mesozoic Floras of New Zealand. Review by A. C. McF. 657

Aspects of Ontogeny in the Study of Ammonite Evolution. By A. E. Truemann 140

Aurousseau, M., and Washington, Henry S. The Nephelite Syenite and Nephelite Porphyry of Beemerville, New Jersey. 571

Baker, Frank Collins. Pleistocene Mollusca from Northwestern and Central Illinois 43

Barrows, Harlan H. Review of World Atlas of Commercial Geology; Part I, Distribution of Mineral Production, by United States Geological Survey 650

Bassler, R. S. Systematic Report on the Cambrian and Ordovician of Maryland. Review by A. C. McF. 84, 176

Bastin, E. S. Editorial 631

———. Reviews . 83, 263, 264, 325, 335, 336, 411, 412, 509, 511, 719, 723

Bather, F. A. Growth-Stages of the Blastoid, *Orophocrinus Stelliformis* 73

Beal, Carl H., and Lewis, J. O. Some Principles Governing the Production of Oil Wells. Review by W. O. G. 264

PAGE

Beger, David B. Geology of Webster County and a Portion of Mingo District, Randolph County, South of Valley Fork of Elk River. Review by A. C. McF. 329
Behavior of Inclusions in Igneous Magmas, The. By N. L. Bowen . 513
Behre, Charles H., Jr. Petrological Abstracts and Reviews . . 401, 714
Benson, W. N. An Outline of the Geology of New Zealand . . . 1
Berry, Edward W. Marine Upper Cretaceous and a New Echinocorys from the altaplaniciae of Bolivia 227
———. Upper Cretaceous Floras of the Eastern Gulf Region in Tennessee, Mississippi, Alabama, and Georgia. Review by A. C. N. 722
Beyschlag, F. The Mineralization of the Copper Shales. Review by E. S. B. 723
Blastoid, *Orophocrinus Stelliformis*, Growth-Stages of the. By F. A. Bather. 73
Bowen, N. L. The Behavior of Inclusions in Igneous Magma . . 513
———. The Reaction Principle in Petrogenesis 177
Bridge, Josiah, and Charles, B. E. A Devonian Outlier near the Crest of the Ozark Uplift 450
Brooks, Alfred H., and LaCroix, Morris F. The Iron and Associated Industries of Lorraine, the Sarre District, Luxemberg, and Belgium. Review by C. H. B., Jr. 655
Brown, John S. Fault Features of Salton Basin, California . . . 217
Bruce E. L. The Early Pre-Cambrian Formations of Northern Ontario and Northern Manitoba 459
Bryan, Kirk. The Hot Water Supply of the Hot Springs, Arkansas . 425
Bulletin No. 36, Illinois State Geological Survey. Review by A. C. McF. 330
Burwash, E. M. The Pre-Cambrian of Western Patricia 393

Cambrian and Ordovician of Maryland, The. By R. S. Bassler. Review by A. C. McF. 84, 176
Cameron, A. E. Post-Glacial Lakes in the Mackenzie River Basin, Northwest Territories, Canada 337
Canu, Ferdinand, and Bassler, Ray S. North American Early Tertiary Bryozoa. Review by A. C. McF.. 261
Case, E. C., and Robinson, W. I. The Geology of Limestone Mountain and Sherman Hill in Houghton County, Michigan. Review by A. C. McF.. 85
Chadwick, G. H. The Paleozoic Rocks of the Canton Quadrangle. Review by J. F. W. 415
Chamberlin, T. C. Memorial Editorial—Rollin D. Salisbury. . . 480
———. Review of Life of James Hall, Geologist and Paleontologist, 1811–1898. By J. M. Clarke. 175
Clarke, J. M. Life of James Hall, Geologist and Paleontologist, 1811–1898. Review by T. C. C. 175

PAGE

Clastic Sediments, a Scale of Grade and Class Terms for. By Chester K. Wentworth 377
Coal. By Elwood S. Moore. Review by C. R. S. 717
Coal in 1918. Part A: Production. By C. E. Lesher. Review by E. S. B. 264
Coal, Oil, Limestone, and Iron Ore Map, New Edition of. By West Virginia Geological Survey. Author's Abstract. 418
Colby, Charles C. Source Book for the Economic Geography of North America. Review by R. D. S. 82
Collins, W. H. An Outline of the Physiographic History of Northeastern Ontario 199
Contact-Metamorphic Tungsten Deposits in the United States. By Frank L. Hess and Esper S. Larsen. Review by E. S. B. . . . 719
Contact Phenomena between Gneiss and Limestone in Western Massachusetts, On. By Pentti Eskola 265
Contributions to the Pre-Cambrian Geology of Northern Michigan and Wisconsin. By R. C. Allen and L. P. Barrett. The Geology of Limestone Mountain and Sherman Hill in Houghton County, Michigan. By E. C. Case and W. I. Robinson. Review by A. C. McF. 85
Cooke, H. C. Geology of the Matachewan District, Northern Ontario. Review by C. H. B., Jr. 424
Copper Deposits of Ray and Miami, Arizona, The. By Frederick Leslie Ransome. Review by E. S. B. and C. H. B. 325
Copper Shales, The Mineralization of the. By F. Beyschlag. Review by E. S. B. 723
Cox, G. H., Dake, C. L., and Muilenburg, G. A. Field Methods in Petroleum Geology. Review by W. O. G. 332
Cressey, George B. Notes on the Sand Dunes of Northwestern Indiana 248
Crinoid Genus Scyphocrinus and Its Bulbous Root Camarocrinus, On the. By Frank Springer. Review by A. C. McF. 259
Criticism of the "Faunal Relationships of the Meganos Group" by Bruce L. Clark, A. By Roy E. Dickerson 295
Crosby, Irving B. Former Courses of the Androscoggin River . . 232
Crystallization and Magmatic Differentiation of Igneous Rocks, The Physical Chemistry of the. V. By J. H. L. Vogt 611
Crystallization and Magmatic Differentiation of Igneous Rocks, The Physical Chemistry of the. VI. By J. H. L. Vogt 659
Crystobalite in California, A New Occurrence of. By Austin F. Rogers 211
Cushman, Joseph A. The American Species of Orthophragmina and Lepidocyclina. Review by A. C. McF. 260

Dake, Charles Laurence. The Problem of the St. Peter Sandstone. Review by R. D. S. 646

PAGE
Davies, A. Morley. An Introduction to Paleontology. Review by C. L. F. 651
Deposits of Manganese Ore in Arizona. By E. L. Jones, Jr., and F. L. Ransome. Review by C. H. B., Jr. 648
Deposits of Manganese Ore in Costa Rica and Panama. By Julian D. Sears. Review by C. H. B., Jr. 653
Deposits of Manganese Ore in the Batesville District, Arkansas, Preliminary Report on the. By Hugh D. Miser. Review by C. H. B., Jr. 501
Deposits of Iron Ore near Stanford, Montana. By L. G. Westgate. Review by E. S. B. 335
Description geométrique des Alpes Françaises, Annexe du Tome second. By P. Helbronner. Review by W. H. Hobbs 717
Detailed Report on Nicholas County [West Virginia.] By David B. Reger. Author's Abstract 419
Devonian Outlier near the Crest of the Ozark Uplift, A. By Josiah Bridge and B. E. Charles 450
Dickerson, Roy E. A Criticism of the "Faunal Relationships of the Meganos Group" by Bruce L. Clark 295
Dinosaur Tracks in Hamilton County, Texas. By W. E. Wrather . 354
Domes and Anticlines in the Lost Soldier-Ferris District, Wyoming, The Age of the. By A. E. Fath 303

Earlier Mesozoic Floras of New Zealand, The. By E. A. Newell Arber. Review by A. C. McF. 657
Early Pre-Cambrian Formations of Northern Ontario and Northern Manitoba, The. By E. L. Bruce 459
Editorial. By E. S. B. 631
Editorial, Memorial. Rollin D. Salisbury. By T. C. C.. 480
Economic Aspects of Geology, The. By C. K. Leith. Review by Edson S. Bastin 511
Economic Geography of North America, Source Book for the. By Charles C. Colby. Review by R. D. S. 82
Eleventh Biennial Report of the State Geologist on the Mineral Industries and Geology of Vermont. By George H. Perkins, *et al.* Review by A. C. McF. 86
Eskola, Pentti. On Contact Phenomena between Gneiss and Limestone in Western Massachusetts 265

Fairchild, Herman L. Pleistocene Submergence of the Hudson, Champlain and St. Lawrence Valleys. Review by J. F. W. . . . 504
Fath, A. E. The Age of the Domes and Anticlines in the Lost Soldier-Ferris District, Wyoming 303
Fault Features of Salton Basin, California. By John S. Brown . . 217
Fault Troughs of the Antilles, The Great. By Stephen Taber . . 89

PAGE

"Faunal Relationships of the Meganos Group" by Bruce L. Clark, A Criticism of the. By Roy E. Dickerson 295

Fay, Albert S. A Glossary of the Mining and Mineral Industry. Review by E. S. B. 263

Ferguson, Henry G. The Mogollon District, New Mexico. Review by C. H. B., Jr. 420

Field Methods in Petroleum Geology. By G. H. Cox, C. L. Dake, and G. A. Muilenburg. Review by W. O. G. 332

Former Courses of the Androscoggin River. By Irving B. Crosby . 232

Foye, Wilbur G. Origin of the Triassic Trough of Connecticut . . 690

Fraser River, British Columbia, Canada, The Character of the Stratification of the Sediments in the Recent Delta of. By W. A. Johnston 115

Gardner's Theory of the Origin of Certain Concretions, In Support of. By Leroy Patton 700

Genesis of the Zinc Ores of Edwards District, St. Lawrence County, New York. By C. H. Smyth, Jr. Review by J. F. W. . . . 418

Geological Survey of Western Australia. Maps and Sections to Accompany Report on Contributions to the Study of the Geology and Ore Deposits of Kalgoorlie, East Coolgardie Goldfield. Review by A. C. McF. 86

Geological Survey of Western Australia. Maps and Sections to Accompany Report on the Geology and Mineral Resources of the Yilgarn Goldfield. Review by A. C. McF. 84

Geological Survey of Western Australia. Maps and Sections to Accompany Report on the Geology and Ore Deposits of Meekatharra, Murchison Goldfield. Review by A. C. McF. 84

Geology and Mineral Deposits of a Part of Amherst Township, Quebec. By M. E. Wilson. Review by J. F. W. 419

Geology of Hardin County and the Adjoining Part of Pope County, The. By Stuart Weller with the collaboration of Charles Butts, L. W. Currier, and R. D. Salisbury. Review by A. C. McF. . . . 257

Geology of New Zealand, An Outline of the. By W. N. Benson . . 1

Geology of Northeastern Rajputana and Adjacent Districts, The. By A. M. Heron. Review by A. C. McF. 176

Geology of the Matachewan District, Northern Ontario. By H. C. Cooke. Review by C. H. B., Jr. 424

Geology of the Non-Metallic Mineral Deposits other than Silicates. Vol. I. Principles of Salt Deposition. By A. W. Grabau. Review by W. T. B. 721

Geology of the Tuapeka District, Central Otago Division, The. By P. Marshall. Review by A. C. McF. 88

Geology of the Yellow Pine Cinnabar District, Idaho. By E. S. Larson and E. C. Livingston. Review by E. S. B. 263

PAGE

Geology of Webster County and a Portion of Mingo District, Randolph County, South of Valley Fork of Elk River. By David B. Beger. Review by A. C. McF. 329

Glacial Loess Accumulation, The Time of, in its Relation to the Climatic Implications of the Great Loess Deposits: Did They Chiefly Accumulate during Glacial Retreat? By Stephen Sargent Visher 472

Glenk, Robert. Louisiana Lignite. Review by C. H. B., Jr.. . . . 262

Glossary of the Mining and Mineral Industry, A. By Albert H. Fay. Review by E. S. B. 263

Goldman, Marcus I. Lithologic Subsurface Correlation in the "Bend Series" of North Central Texas. Review by C. H. B., Jr. . . . 333

Grabau, A. W. Geology of the Non-Metallic Mineral Deposits other than Silicates. Vol. I. Principles of Salt Deposition. Review by W. T. B. 721

Grade and Class Terms for Clastic Sediments, A Scale of. By Chester K. Wentworth 377

Great Fault Troughs of the Antilles, The. By Stephen Taber . . 89

Gypsum Deposits of the United States. By R. W. Stone. Review by F. P. S. 327

Gypsum in 1919. By R. W. Stone. Review by E. S. B. 336

Harder, Edmund Cecil. Iron Depositing Bacteria and Their Geological Relations. Review by C. H. B., Jr. 506

Hayes, A. O. The Malagash Salt Deposit, Cumberland County, Nova Scotia. Review by J. F. W. 82

Helbronner, P. Description geométrique des Alpes Françaises, Annexe du Tome second. Review by W. H. Hobbs 717

Helium-Bearing Natural Gas. By G. Sherburne Rogers. Review by E. S. Bastin 509

Heron, A. M., B.Sc., F.G.S. The Geology of Northeastern Rajputana and Adjacent Districts. Review by A. C. McF. 176

Hess, Frank L. Tungsten in 1918. Review by E. S. B. and C. H. B., Jr. 423

Hess, Frank L., and Larsen, Esper S. Contact-Metamorphic Tungsten Deposits in the United States. Review by E. S. B. 719

Hobbs, W. H. Review of Description geométrique des Alpes Françaises, Annexe du Tome second, by P. Helbronner 717

Hot Water Supply of the Hot Springs, Arkansas, The. By Kirk Bryan 425

Igneous Rocks, On the Representation of, in Triangular Diagrams. By Albert Johannsen 167

Igneous Rocks, The Physical Chemistry of the Crystallization and Magmatic Differentiation of. V. By J. H. L. Vogt 611

Igneous Rocks, The Physical Chemistry of the Crystallization and Magmatic Differentiation of. VI. By J. H. L. Vogt 659

PAGE

Inclusions in Igneous Magmas, The Behavior of. By N. L. Bowen . 513
Informational Corrugated Rocks. By William J. Miller 587
Introduction to Paleontology, An. By A. Morley Davies. Review by C. L. F. 651
Iron and Associated Industries of Lorraine, the Sarre District, Luxemburg, and Belgium, The. By Alfred H. Brooks and Morris F. LaCroix. Review by C. H. B., Jr. 655
Iron Depositing Bacteria and Their Geological Relations. By Edmund Cecil Harder. Review by C. H. B., Jr. 506

Jack, R. Lockhart, B.E., F.G.S. The Phosphate Deposits of South Australia. Review by A. C. McF. 176
Johannsen, Albert. On the Representation of Igneous Rocks in Triangular Diagrams 167
Johannsen, Albert, and Charles H. Behre, Jr. Petrological Abstracts and Reviews 170, 252, 319, 401, 482, 632, 703
Johnson, W. E. Map of the North Pacific. Review 420
Johnston, W. A. The Character of the Stratification of the Sediments in the Recent Delta of Fraser River, British Columbia, Canada . 115
Jones, E. L., Jr., and Ransome, F. L. Deposits of Manganese Ore in Arizona. Review by C. H. B., Jr. 648

Kalgoorlie, East Coolgardie Goldfield, Maps and Sections to Accompany Report on Contributions to the Study of the Geology and Ore Deposits of. By Geological Survey of Western Australia. Review by A. C. McF. 86

Lane, Alfred C. Segregation Granites. 162
Larson, E. S., and Livingston, E. C. Geology of the Yellow Pine Cinnebar District, Idaho. Review by E. S. B. 263
la Touche, T. H. D., M.A., F.G.S. (Compiler). An Annotated Index of Minerals of Economic Value, to Accompany a Bibliography of Indian Geology and Physical Geography. Review by A. C. McF. 88
Leith, C. K. The Economic Aspects of Geology. Review by Edson S. Bastin. 511
Lesher, C. E. Coal in 1918. Part A: Production. Review by E. S. B. 264
Life of James Hall, Geologist and Paleontologist, 1811–1898. By J. M. Clarke. Review by T. C. C.. 175
Limestone and Phosphate Resources of New Zealand, The. Part I. Limestone. By P. G. Morgan. Review by E. S. B. 83
Limestone Mountain and Sherman Hill in Houghton County, Michigan, The Geology of. By E. C. Case and W. I. Robinson. Review by A. C. McF. 85

PAGE

Lithologic Subsurface Correlation in the "Bend Series" of North Central Texas. By Marcus I. Goldman. Review by C. H. B., Jr. 333
Longwell, Chester R. The Muddy Mountain Overthrust in Southeastern Nevada 63
Lost Soldier-Ferris District, Wyoming, The Age of the Domes and Anticlines in the. By A. E. Fath. 303
Louisiana Lignite. By Robert Glenk. Review by C. H. B., Jr. . . 262

MacCarthy, Gerald R. Mud Cracks on Steeply Inclined Surfaces . 702
MacClintock, Paul. The Pleistocene History of the Lower Wisconsin River 673
McLennan, J. C., and Associates. Report on Some Sources of Helium in the British Empire. Review by E. S. B. 411
Magnetite Deposits of Grenville District, Argenteuil County, Quebec. By M. E. Wilson. Review by J. F. W. 503
Malagash Salt Deposit, Cumberland County, Nova Scotia, The. By A. O. Hayes. Review by J. F. W. 82
Manganese Ore in Arizona, Deposits of. By E. L. Jones, Jr., and F. L. Ransome. Review by C. H. B., Jr. 648
Manganese Ore in the Batesville District, Arkansas, Preliminary Report on the Deposits of. By Hugh D. Miser. Review by C. H. B., Jr. 501
Map of the North Pacific. By W. E. Johnson. Review. 420
Maps and Sections to Accompany Report on Contributions to the Study of the Geology and Ore Deposits of Kalgoorlie, East Coolgardie Goldfield. By Geological Survey of Western Australia. Review by A. C. McF. 86
Maps and Sections to Accompany Report on the Geology and Mineral Resources of the Yilgarn Goldfield. By Geological Survey of Western Australia. Review by A. C. McF. 84
Maps and Sections to Accompany Report on the Geology and Ore Deposits of Meekatharra, Murchison Goldfield. By Geological Survey of Western Australia. Review by A. C. McF. 84
Marine Upper Cretaceous and a New Echinocorys from the Altaplanicie of Bolivia. By Edward W. Berry. 227
Marshall, P., M.A., D.Sc., F.G.S. The Geology of the Tuapeka District, Central Otago Division. Review by A. C. McF. . . . 88
Martin, James C. The Pre-Cambrian Rocks of the Canton Quadrangle. Review by J. F. W. 416
Meekatharra, Murchison Goldfield, Maps and Sections to Accompany Report on the Geology and Ore Deposits of. By Geological Survey of Western Australia. Review by A. C. McF. 84
Mehl, Maurice G. A New Phytosaur from the Trias of Arizona . . 144
Memorial Editorial—Rollin D. Salisbury. By T. C. C. 480

PAGE

Miller, William J. Intraformational Corrugated Rocks 587
Mineral Resources of Michigan for 1914 and Prior Years. Prepared under the direction of R. C. Allen. With a treatise on Michigan copper deposits by R. E. Hore. Review by D. J. F. . . . 332
Mineral Resources of Michigan for 1917 and Prior Years. Prepared under the direction of R. C. Allen. Review by D. J. F. . . . 332
Mineral Resources of the Philippine Islands for the Years 1917 and 1918, The. Contributors: Elmer D. Merrill, Victoriano Elicano, Leopoldo A. Faustino, W. H. Overbeck, and T. Dar Juan. Review by C. H. B., Jr. 652
Miser, Hugh D. Preliminary Report on the Deposits of Manganese Ore in the Batesville District, Arkansas. Review by C. H. B., Jr. 501
Mogollon District, New Mexico, The. By Henry G. Ferguson. Review by C. H. B., Jr. 420
Moore, Elwood S. Coal. Review by C. R. S. 717
Moore, Raymond C., and Plummer, Frederick B. Pennsylvanian Stratigraphy of North Central Texas 18
Morgan, P. G. The Limestone and Phosphate Resources of New Zealand. Part I. Limestone. Review by E. S. B. 83
Mud Cracks on Steeply Inclined Surfaces. By Gerald R. MacCarthy 702
Muddy Mountain Overthrust in Southeastern Nevada, The. By Chester R. Longwell 63

Nephelite Syenite and Nephelite Porphyry of Beemerville, New Jersey, The. By M. Aurousseau and Henry S. Washington . . . 571
New Edition of Coal, Oil, Gas, Limestone, and Iron Ore Map. By West Virginia Geological Survey. Author's Abstract . . . 418
New Zealand, An Outline of the Geology of. By W. N. Benson . . 1
Non-Metallic Mineral Deposits other than Silicates, Geology of the. Vol. I. Principles of Salt Deposition. By A. W. Grabau. Review by W. T. B. 721
North American Early Tertiary Bryozoa. By Ferdinand Canu and Ray S. Bassler. Review by A. C. McF. 261

O'Harra, Cleophus C. The White River Badlands. Review by R. D. S. 331
Ontogeny in the Study of Ammonite Evolution, Aspects of. By A. E. Trueman 140
Origin of the Triassic Trough of Connecticut. By Wilbur G. Foye . 690
Orophocrinus Stelliformis, Growth-Stages of the Blastoid. By F. A. Bather 73
Outline of the Physiographic History of Northeastern Ontario, An. By W. H. Collins 199

PAGE

Paleontology, An Introduction to. By A. Morley Davies. Review by C. L. F. 651
Paleozoic Bituminous Coals, Structure in. By Reinhardt Thiessen. Review by A. C. N. 718
Paleozoic Rocks of the Canton Quadrangle, The. By G. H. Chadwick. Review by J. F. W. 415
Patton, Leroy. In Support of Gardner's Theory of the Origin of Certain Concretions 700
Pennsylvanian Stratigraphy of North Central Texas. By Raymond C. Moore and Frederick B. Plummer 18
Perkins, George H., *et al.* Eleventh Biennial Report of the State Geologist on the Mineral Industries and Geology of Vermont. Review by A. C. McF. 86
Petrogenesis, The Reaction Principle in. By N. L. Bowen. 177
Petrological Abstracts and Reviews . . 170, 252, 319, 401, 482, 632, 703
Physical Chemistry of the Crystallization and Magmatic Differentiation of Igneous Rocks, The. V. By J. H. L. Vogt 611
Physical Chemistry of the Crystallization and Magmatic Differentiation of Igneous Rocks, The. VI. By J. H. L. Vogt 659
Physiographic History of Northeastern Ontario, An Outline of the. By W. H. Collins 199
Phosphate Depostis of South Australia, The. By R. Lockhart Jack, B.E., F.G.S. Review by A. C. McF. 176
Phytosaur from the Trias of Arizona, A New. By Maurice G. Mehl . 144
Pleistocene History of the Lower Wisconsin River, The. By Paul MacClintock 673
Pleistocene Marine Submergence of the Hudson, Champlain and St. Lawrence Valleys. By Herman L. Fairchild. Review by J. F. W. 504
Pleistocene Mollusca from Northwestern and Central Illinois. By Frank Collins Baker. 43
Possible Silurian Tillite in Southeastern British Columbia. By Francis P. Shepard 77
Post-Glacial Lakes in the Mackenzie River Basin, Northwest Territories, Canada. By A. E. Cameron. 337
Potash Recovery at Cement Plants. By Alfred W. G. Wilson. Review by E. S. B. 412
Pre-Cambrian of Western Patricia, The. By E. M. Burwash. . . . 393
Pre-Cambrian Rocks of the Canton Quadrangle, The. By James C. Martin. Review by J. F. W. 416
Principles Governing the Production of Oil Wells, Some. By Carl H. Beal and J. O. Lewis. Review by W. O. G. 264
Problem of the St. Peter Sandstone, The. By Charles Laurence Dake. Review by R. D. S. 646

PAGE

Problems in Stratigraphy along the Rocky Mountain Trench. By Francis Parker Shepard 361
Proceedings of the Coal Mining Institute of America. Review by E. S. B. 411
Purcell Range and the Rocky Mountains of Canada, The Structural Relation of the. By Francis Parker Shepard 130

Ransome, Frederick Leslie. The Copper Deposits of Ray and Miami, Arizona. Review by E. S. B. and C. H. B. 325
Reaction Principle in Petrogenesis, The. By N. L. Bowen . . . 177
Reger, David B. Detailed Report on Nicholas County [West Virginia.] Author's Abstract 419
Report on Mining Operations in the Province of Quebec, 1919. Review by E. S. B. 335
Report on Some Sources of Helium in the British Empire. By J. C. McLennan and Associates. Review by E. S. B. 411
Reviews 82, 175, 257, 325, 411, 501, 646, 717
Rocky Mountain Trench, Problems in Stratigraphy along the. By Francis Parker Shepard 361
Rogers, Austin F. A New Occurrence of Crystobalite in California . 211
Rogers, G. Sherburne. Helium-Bearing Natural Gas. Review by E. S. Bastin 509
Rollin D. Salisbury—Memorial Editorial. By T. C. C. 480
Ruedemann, Rudolf. On the Occurrence of an Apus in the Permian of Oklahoma 311

St. Peter Sandstone, The Problem of the. By Charles Laurence Dake. Review by R. D. S. 646
Salisbury, Rollin D.—Memorial Editorial. By T. C. C. 480
———. Review of Source Book for the Economic Geography of North America. By Charles C. Colby 82
———. Review of the Problem of the St. Peter Sandstone. By Charles Laurence Dake. 646
———. Review of the White River Badlands. By Cleophus C. O'Harra 331
Sand Dunes of Northwestern Indiana, Notes on the. By George B. Cressey 248
Scale of Grade and Class Terms for Clastic Sediments, A. By Chester K. Wentworth 377
Sears, Julian D. Deposits of Manganese Ore in Costa Rica and Panama. Review by C. H. B., Jr. 653
Sediments in the Recent Delta of Fraser River, British Columbia, Canada, The Character of the Stratification of the. By W. A. Johnston 115

PAGE
Segregation Granites. By Alfred C. Lane 162
Shepard, Francis P. Possible Silurian Tillite in Southeastern British Columbia 77
———. Problems in Stratigraphy along the Rocky Mountain Trench 361
———. The Structural Relation of the Purcell Range and the Rocky Mountains of Canada 130
Short-Bellows, Roll-Film Kodak for Detail Work in the Field, Adapting a. By Chester K. Wentworth 158
Smyth, Jr., C. H. Genesis of the Zinc Ores of Edwards District, St. Lawrence County, New York. Review by J. F. W.. . . . 418
Source Book for the Economic Geography of North America. By Charles C. Colby. Review by R. D. S. 82
Springer, Frank. On the Crinoid Genus Scyphocrinus and Its Bulbous Root Camarocrinus. Review by A. C. McF. 259
Stone, R. W. Gypsum Deposits of the United States. Review by F. P. S. 327
———. Gypsum in 1919. Review by E. S. B. 336
Stratification of the Sediments in the Recent Delta of Fraser River, British Columbia, Canada, The Character of the. By W. A. Johnston 115
Stratigraphy along the Rocky Mountain Trench, Problems in. By Francis Parker Shepard 361
Structural Relation of the Purcell Range and the Rocky Mountains of Canada, The. By Francis Parker Shepard 130
Structure in Paleozoic Bituminous Coals. By Reinhardt Thiessen. Review by A. C. N. 718
Systematic Report on the Cambrian and Ordovician of Maryland. By R. S. Bassler. Review by A. C. McF. 176

Taber, Stephen. The Great Fault Troughs of the Antilles . . . 89
Thiessen, Reinhardt. Structure in Paleozoic Bituminous Coals. Review by A. C. N. 718
Timiskaming County, Quebec. By M. E. Wilson. Review by J. F. W. 413
Triassic Trough of Connecticut, Origin of the. By Wilbur G. Foye . 690
Trueman, A. E. Aspects of Ontogeny in the Study of Ammonite Evolution 140
Tungsten Deposits in the United States, Contact-Metamorphic. By Frank L. Hess and Esper S. Larsen. Review by E. S. B. . . 719
Tungsten in 1918. By Frank L. Hess. Review by E. S. B. and C. H. B., Jr. 423

United States Geological Survey. World Atlas of Commercial Geology; Part I, Distribution of Mineral Production. Review by Harlan H. Barrows. 650

PAGE

Upper Cretaceous Floras of the Eastern Gulf Region in Tennessee, Mississippi, Alabama, and Georgia. By E. W. Berry. Review by A. C. N. 722

Visher, Stephen Sargent. The Time of Glacial Loess Accumulation in Its Relation to the Climatic Implications of the Great Loess Deposits: Did they Chiefly Accumulate during Glacial Retreat? . 472
Vogt, J. H. L. The Physical Chemistry of the Crystallization and Magmatic Differentiation of Igneous Rocks. V 611
VI 659

Weller, Stuart, with the collaboration of Charles Butts, L. W. Currier, and R. D. Salisbury. The Geology of Hardin County and the Adjoining Part of Pope County. Review by A. C. McF. . . 257
Wentworth, Chester K. Adapting a Short-Bellows, Roll-Film Kodak for Detail Work in the Field 158
———. A Scale of Grade and Class Terms for Clastic Sediments. . 377
Westgate, L. G. Deposits of Iron Ore near Stanford, Montana. Review by E. S. B. 335
West Virginia Geological Survey. New Edition of Coal, Oil, Limestone, and Iron Ore Map. Author's Abstract 418
White River Badlands, The. By Cleophus C. O'Harra. Review by R. D. S. 331
Wilson, Alfred W. G. Potash Recovery at Cement Plants. Review by E. S. B. 412
Wilson, M. E. Geology and Mineral Deposits of a Part of Amherst Township, Quebec. Review by J. F. W. 419
———. Magnetite Deposits of Grenville District, Argenteuil County, Quebec. Review by J. F. W. 503
———. Timiskaming County, Quebec. Review by J. F. W. . . 413
World Atlas of Commercial Geology; Part I, Distribution of Mineral Production. By Unites States Geological Survey. Review by Harlan H. Barrows 650
Wrather, W. E. Dinosaur Tracks in Hamilton County, Texas . . 354

Yilgarn Goldfield, Maps and Sections to Accompany Report on the Geology and Mineral Resources of the. By Geological Survey of Western Australia. Review by A. C. McF. 84

Zinc Ores of Edwards District, St. Lawrence County, New York, Genesis of the. Review by J. F. W. 418